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A Survey of K, L and M X-Ray
Absorption Limit Measurements

by

Lieutenant Gary David Matthews, U.S. Navy
//

An essay submitted to the Faculty of Philosophy
of the Johns Hopkins University in conformity
with the requirements for the degree of
Master of Arts

Baltimore, Maryland
1964

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Acknowledgements

This essay, like all scientific endeavors, is not the work of the author alone, but of a great many people: my parents, who have followed my studies and work with never failing interest and encouragement since boyhood; the many teachers who have patiently guided and taught me; the curious from generations past and present, who, in the long search for more accurate knowledge, have laid the ground work and provided the material upon which my own small offering has been based, and those who have aided in its preparation. The time and financial assistance necessary for the advanced studies which have made the essay possible were provided through the Office of Naval Research, under the postgraduate program sponsored by the United States Navy.

I am especially indebted to Dr. J. A. Bearden and Dr. J. S. Thomsen, under whose direction this work was carried out. Without their ever available guidance, encouragement and patient assistance it could not have been completed.

I also wish to thank my fellow students at the Rowland Physical Laboratory for many interesting discussions and suggestions. In particular, I wish to express my gratitude to Alex Burr and Ralph Stevens for their aid in reading the original draft and in pointing out several errors.

Finally, I owe much to my wife Trudy for her untiring assistance with the many tedious calculations and clerical work, and most of all for her continuing confidence and understanding.

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I. Introduction

This report presents the results of a critical review of measured low energy, or long wavelength limits in the K, L and M discontinuities of x-ray absorption spectra, covering the wavelength range from approximately 0.1 to 15 angstroms. The purpose of the survey has been to offer a table including all recent determinations of these "absorption limit" wavelengths and, on the basis of our evaluation, to recommend in each case that value considered as most nearly correct. In addition, values of the wave number in inverse x-units, the square root of this number, and the quantum energy value corresponding to each recommended wavelength have been calculated and are included in the tables of section VI.

Because x-ray absorption spectra depend on the chemical and physical state of the absorber, each element presents a variety of spectra, many of which have never been investigated, and each with discontinuities which differ in structural detail. To treat all of these is beyond the scope of this report, which is concerned primarily with the pure elemets in their solid state. In a number of instances however, a particular element, or group of elements such as the rare earths, have been

extensively investigated only in compound form, or, as for the inert gases, in other than the solid state, and these measurements have been evaluated for cases of this nature.

Modified Moseley diagrams have been used extensively in the evaluation process and, in a number of instances, to obtain interpolated values. A complete set are included as appendix A. Much of the detail has of course been lost in the reproduction, due to the necessity of reducing the scale; nevertheless, they provide an excellent means of illustrating the relative accuracy of the measurements. Most of those measurements studied are plotted on these diagrams, which are discussed at some length in section III.

II. Theory and Experimental Techniques

In principle, the structure of an absorption discontinuity reveals information concerning unoccupied levels belonging to the Fermi or valence band, or to the crystal lattice of the absorbing material. Unfortunately, many factors complicate accurate registration and interpretation of the absorption spectra in the wavelength regions of these discontinuities.

It is not the purpose of this report to present a detailed account of either the theory involved in x-ray absorption phenomena, or of the experimental techniques of registration and measurement[1], and only a few of the more important aspects relating to precision of the measurements and accuracy of the values obtained are mentioned here.

Early investigations (most of those prior to 1930) were carried out utilizing single crystal spectrographs of rather low resolving power. The resulting photographic records revealed discontinuities in the form of comparatively sharp edges, often preceded by a more or less pronounced peak in the transmitted intensity. Within the accuracy obtainable at that time, these

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[1] For a complete discussion of these subjects, the interested reader is referred to the work by Sandstrom (95). In addition to a thorough review of theory and experimental techniques, this work contains an excellent bibliography listing many books and articles of general interest in the field of x-ray spectroscopy.

"edges", as they were quite naturally called, were correctly interpreted as belonging to the limit of photoelectric absorption for a particular electronic shell or subshell. In the late twenties and early thirties, the double crystal and bent crystal spectrometers were developed, which, with certain modifications and improvements, have since come to be used almost exclusively for precision x-ray spectroscopic work. The significantly greater resolving power of these instruments has revealed a wealth of structural detail in the so called "edges" and adjacent regions of the spectra, which has in turn raised numerous questions concerning the theoretical interpretation.

Before proceeding further with the present discussion, it is appropriate to digress slightly at this point to define several terms used throughout this report with relation to the above mentioned structure. The definitions given below are for the most part those generally accepted; however, the terms are often used somewhat vaguely, or with slightly different connotation in the literature.

Absorption Discontinuity - the general region of an x-ray absorption spectra in which the transmitted intensity, hence coefficient of absorption, varies abruptly (almost discontinuously) with wavelength.

Absorption Edge - that portion of an absorption discontinuity extending in general, from the minimum of transmitted intensity (maximum absorption coefficient) toward longer wavelengths, to the maximum of transmitted intensity (minimum absorption coefficient). In a few instances, the shape of a discontinuity is such that this definition cannot be strictly applied. A more appropriate definition might be - that portion of a discontinuity which appears as a sharp edge when viewed with a spectrometer of low resolving power. Except in those cases where two edges appear so closely spaced in wavelength that their structures overlap, the edge joins to the smoothly varying portion of the spectra on the long wavelength side.

Absorption Limit - the inflection point of longest wavelength in any curve representing an absorption edge[2]. In many instances, and particularly in the case of gaseous absorbers, this is the inflection

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[2] The reader familiar with the subject will note that the wavelength position of an absorption limit depends to a small degree on whether it is taken from an absorption coefficient curve, or from a curve representing transmitted intensity. This difference is discussed later in this section as well as in section IV, and is the subject of appendix B.

point of the edge itself, however the structure of an edge is usually more complicated and most often appears step like in form.

Main Edge - that portion of the absorption edge which includes the absorption limit. This term is used to distinguish between the longest wavelength "step" and secondary edges, or remaining "steps" in an edge having this type of structure.

Fine Structure - all structure in an absorption discontinuity falling to the short wavelength side of the edge[3].

One of the most basic problems involving the interpretation of the structural details in absorption discontinuities has been the question: What, if any, characteristic feature of the edge actually belongs to a transition into the first available, exterior level? Richtmyer, Barnes and Ramberg (83) treated this question theoretically in 1934, using as a basis, the Weisskopf - Wigner theory of spectral line shapes applied to absorption. For the simplest case, they assumed that the region of high absorption on the short wavelength side of a main edge is the result of a superposition of equally spaced,

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[3] The fine structure is generally divided into two types, which are discussed in detail by Sandstrom (95). Since it is not necessary for our purposes, the two types are not distinguished here.

identical absorption lines. Their result was that the absorption coefficient in the vicinity of a main edge should vary with wavelength, or frequency, according to an arctangent curve of the form

$$\mu(\nu) = \text{CONST.} \left\{ \frac{1}{2} - \frac{1}{\pi} \text{ ARCTAN} \left(\frac{\nu_{E_0A} - \nu}{\Gamma_E/2} \right) \right\}. \qquad (\text{II} - 1)$$

Here $\mu(\nu)$ is the absorption coefficient, ν_{E_0A} the frequency difference between the initial state and first unoccupied level, and Γ_E is the full width at half maximum of each absorption line. A more complicated equation was obtained when they considered absorption by a metal, with a level distribution corresponding to that of a Fermi gas of free electrons. The two curves very nearly correspond however, differing at the inflection point by only a fraction of an electron volt. Equation (II - 1) has never been explicitly verified experimentally; nevertheless, its value has been great, if for no other reason than that it has served to provide a standard in the analysis of results. Since its publication, most investigators who have utilized ionization, or counter techniques for registration of absorption spectra have sought the best fit between an arctan curve and the experimentally determined absorption coefficient curve in the region of a main edge. When such a fit is found, as is normally the case, the resulting inflection point (absorption limit) is generally accepted as the best

answer to the question posed above. In some cases. investigators have measured the absorption limit directly, without actually determining an arctangent fit; however, the main edge is nearly always of a general arctangent form.

The interpretation of absorption coefficient curves in the region of an edge is discussed in detail by Parratt (109) in an interesting paper published in 1959. According to his conclusions, based on a consideration of the creation of excitation states, wave function symmetries, and the selection rules for transitions, the energy corresponding to an absorption limit should either be less than or greater than the normal binding energy of an electron in its initial undisturbed state, depending on whether a transition to the Fermi level is allowed or forbidden.

Experimental attempts to verify the interpretation of an absorption limit as corresponding to the absorption transition of minimum energy have been confined primarily to comparing the values of h/e obtained by other methods, with results calculated from the minimum excitation voltage, V, of emission lines and frequency, ν , of the absorption limit which have respectively, final and initial levels in common using the relationship $eV = h\nu$. In 1941, Bearden and Schwarz (113) reported a result for

h/e determined by this method of:

$$h/e = 1.3795 \pm 0.0010 \times 10^{17} \text{ erg. sec./e.s.u.}$$

More recently, Nilsson (108) obtained an average value of:

$$h/e = 1.3794 \pm 0.0006 \times 10^{17} \text{ erg. sec./e.s.u.},$$

the error being a limit of error. His results were based on an extensive investigation of K excitation potentials for 26 Fe, 27 Co, 28 Ni and 29 Cu emission lines and the corresponding absorption limit values from Beeman and Friedman (7).

While results obtained in this manner agree reasonably well within combined errors with those determined by other methods, the uncertainties involved are quite large by comparison to the precision of recent absorption limit measurements. The limit of error attributed by Nilsson to the voltage determination alone is 280 ppm, whereas his estimate of the combined error for wavelength determination in x-units and conversion to absolute units is only 60 ppm.

The results of a more recent investigation of the same problem were published by Nordfors (78) in 1961. In this paper, he compares the binding energies of ejected photo electrons, measured relative to the Fermi level by Nordling, Bergvall and Hörnfeldt (110, 111), with recent absorption limit measurements by Nordfors

and Nordland (76, 77), which are taken from absorption coefficient curves, for the L_I, L_{II} and L_{III} levels of 47 Ag to 52 Te. The comparison is carried out by means of a modified Moseley plot and within the estimated limits of combined error (approximately 0.4 ev, or about 100 ppm), there is no consistent difference found between the two sets of values for the L_I and L_{III} levels. Lack of agreement for the L_{II} levels is attributed to low accuracy in the absorption limit measurements, due to distortion of the L_{II} edges by overlapping fine structure of the L_{III} discontinuities.

In view of the accepted interpretation of an absorption limit (and, in particular, the predictions of Parratt (109) discussed above), Nordfors (78) considers this close agreement rather surprising and a more extensive investigation seems highly desirable before drawing definite conclusions concerning the results. Nordfors does not state what value was used for conversion from wavelength in x-units to energy units, which could account, in part at least, for the somewhat unexpected results.

To briefly summarize this discussion of interpretation, it appears that the question of exactly what meaning should be assigned to the value of an absorption limit, is still open for discussion. Until the question is

resolved, the primary value of modern precision determinations of absorption limits remains that of relative comparison.

So far, we have been concerned exclusively with the absorption limit as obtained from absorption coefficient curves. Unfortunately, the majority of x-ray absorption studies, until recently at least, have been carried out using photographic registration. This method does not involve statistical counting errors, and has the advantage of simultaneous registration of all wavelengths within a rather wide range and is thus not sensitive to variations of the incident intensity with time. Interpretation of structure in the discontinuities recorded photographically is more difficult however, than in the case of absorption coefficient curves. This is due largely to nonlinearity of the intensity - blackening curve. Except for some of the investigations prior to 1930, measurements of the absorption limit obtained by the photographic technique have generally been made directly on photometric curves of the discontinuities. These are essentially transmitted intensity versus wavelength curves; however, the density curve for the photographic emulsion is seldom taken into consideration, so that accurate interpretation of precision measurements of this type is sometimes obscured.

In addition to the difficulties involving interpretation and the usual technical problems associated with crystal spectrometers[4], there is the problem of producing the spectra. Except in the case of gases, this involves the use of very thin absorbing screens. As was noted in the introduction, the structure in an absorption edge, including the position of the absorption limit, depends on the chemical and physical state of the absorber. For this reason, production of the screens involves numerous technical difficulties.

Sandstrom (95) lists the most common procedures for their manufacture as follows:

> 1. Milling of thin sheets of material, mostly employed for metals in the region of short and medium wavelengths.
> 2. Coating some carrier with a layer of the material in finely powdered form. As carriers, very thin paper or foils of plastic materials are commonly used. Aluminum foils some microns thick are also often employed. The Carrier itself must have a low absorption in the wavelength region to be investigated.
> 3. Mixing a fine powder of the material with a solution of cellulose acetate. The mixture is poured onto a glass plate. When the solvent has evaporated, the thin sheet can be removed by putting the glass plate in water. The cellulose acetate film will then come off very easily.

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[4] To our knowledge, grating measurements have never been made of absorption limits in the wavelength region covered by this report.

4. Evaporating the material onto a carrying foil by means of a vacuum furnace. This technique has been developed during the last two decades on a commercial basis. As carriers plastic materials are to be preferred, since it is possible to remove them, if necessary, after the formation of the absorber.
5. Soluble chemical compounds can be soaked into very thin paper.

As pointed out in the succeeding paragraph by Sandstrom (95), "none of these methods guarantees against contamination." Elements which oxidize readily constitute a particularly difficult group to measure in their pure form and most often the oxide form is used.

Until recently, the thickness of an absorber was not thought to have any effect on the shape of an absorption edge and before 1957, investigators generally sought that thickness for which the product μx in the relation $I = I_0 e^{-\mu x}$ gave maximum contrast at an edge, where μ is the absorption coefficient, x the thickness, and I/I_0 the relative intensity. The sharpness of contrast obtained is of course an important factor in the precision of a measurement. Several criteria have been used to determine optimum thickness for this purpose, but in general, "trial and error" has most often been the deciding factor.

In a 1957 article, Parratt, Hempstead and Hossen (80) have pointed out that thickness of the absorber influences both the shape of structure in and near an edge and the position of the absorption limit. This is shown to be a result of the so called "tails" in the combined spectral window function of the crystal and spectrometer geometry, which play a significant role in the region of an edge due to the large asymmetry. The effect is to cause a shift in the true value of an absorption limit toward shorter wavelengths. The magnitude of the shift is impossible to calculate, since the window function in the all important "tail" region cannot be determined; however, the indication is that an optimum thickness for accurate absorption structure measurements is considerably less than that which maximizes the contrast.

Relatively few experimental investigations have been carried out to determine how large a shift results from this "thickness effect". Only those of Beckman, Axelsson and Bergvall (6, 8), carried out for the K absorption of 74 W and 79 Au, appear to have given definite results. In the case of gold, they observed an approximately linear shift of -0.02 XU/0.1 mm for 4 absorbers of thickness from 0.2 to 0.02 mm. A similar result was obtained for Tungsten of -0.04 XU/0.1 mm for thicknesses of less than 0.2 mm.

Worth noting here is a comparison between the absorption limit value obtained from a curve of absorption coefficient versus wavelength and that observed on the corresponding curve of relative intensity versus wavelength, which is shown by Beckman, Axelsson and Bergvall (6) for the gold K limit. The intensity transmission curve in this case gave a result of approximately 0.03 XU longer wavelength (opposite in direction to the "thickness effect").

With few exceptions, measurements of the absorption limits have been carried out relative to known emission line peaks.

III. Evaluation of the Measurements

The Modified Moseley Diagrams. The primary method for evaluating measured absorption limit values has been through utilization of modified Moseley diagrams. These were constructed in the following manner:

(a) An inverse wavelength, or wave number, $\tilde{\nu}$ in XU^{-1} was calculated for each measurement, using in most cases, the published wavelengths. The exceptions were some of the older measurements, which were first corrected for errors in the value assigned to the emission line peaks used as reference lines[5], and a few cases where values of $\tilde{\nu}$ were calculated from a combination of absorption and emission data. The reason for not correcting more than a few of the measurements was mainly the fact that the majority of articles reviewed did not provide sufficiently specific information concerning reference lines; however, in most cases the values for reference emission lines used by investigators since 1930 agree, within the limits of error for the absorption measurements, with the most recent values from reference (107). The wave numbers for absorption

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[5] Corrected values for the reference lines were taken in all cases from reference 107.

limits calculated from absorption and emission data of the same element are obtained from the relationship:

$$\tilde{\nu}_0 = \tilde{\nu}_{Abs} \pm \tilde{\nu}_{Em}$$

where $\tilde{\nu}_0$ is the wave number of the desired absorption limit, $\tilde{\nu}_{Abs}$ is the wave number of a reference absorption limit known with relatively high accuracy, and $\tilde{\nu}_{Em}$ is the wave number of the emission line arising from a transition between the initial levels for absorption corresponding to $\tilde{\nu}_0$ and $\tilde{\nu}_{Abs}$[6]. The plus or minus sign depends of course on the relative energies of the levels involved. This method has been used only for the heavier elements, where it is reasonable to assume that the energy difference of final states for absorption is small compared to the error in the absorption limit energy.

(b) The average slope of $\sqrt{\tilde{\nu}}$ versus atomic number Z for each of the K, L and M absorption limits was then calculated for groups of from 8 to 18 elements and the equation for a straight line, roughly approximating the variation of experimental points, determined for each group. The grouping of elements

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[6] The values used for $\tilde{\nu}_{Abs}$ have been taken from the tables of section VI and those for $\tilde{\nu}_{Em}$ were calculated from the values given in reference 107.

was decided largely by the outer electronic configuration of the atoms; in most cases the elements in a group have vacancies in the same or adjacent electronic subshells. Thus the deviation of experimental points from the approximate straight line are small.

(c) To obtain the modified Moseley diagrams as they appear in appendix A, these deviations from a straight line of the experimentally determined values for $\sqrt{\tilde{\nu}}$ have been plotted versus Z, using a set of symbols which indicate the type of spectrometer employed for the original wavelength measurement.[7] Fitting of the curves to the resulting points was done visually, taking into account, reliability of the data and variations of electronic configuration with increasing atomic number.

The preferred procedure followed in constructing the modified Moseley curves was to rely to a large extent on measurements selected for their accuracy during the course of reviewing the many articles in which absorption limit wavelength measurements have been published. These were primarily, but not always, those very recently carried out, and the wavelengths, which are considered

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[7] The key to symbols appearing on the modified Moseley diagrams is given in appendix A.

to be significantly more accurate than others of a particular absorption limit for a group of elements, are noted accordingly in the tables of section VI[8].

Unfortunately, only a few such measurements are available and in general the curves are essentially a best fit to the available experimental points; although, very old measurements and those, which for no readily apparent reason fall considerably off of the curve through remaining points, have been largely disregarded. Because the methods used to construct the curves have not always been strictly consistent, or obvious, it is difficult to discuss them in general terms. Since they directly reflect our estimate of the most accurate absorption limit values, much of the remainder of this section is devoted to a discussion of methods and facts utilized in determining their most probable form.

Evaluation of the measurements has started with the basic assumption that the true values of $\sqrt{\tilde{\nu}}$ for a given absorption limit should vary with atomic number according to a uniformly smooth curve for each group of elements over which the electronic shells or subshells fill uniformly. An abrupt change in slope, or "break", in the curve is to be expected, however, at elements in

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[8] Notation used in the tables is explained in section V.

which a shell, or subshell becomes filled. For example, consider the K absorption limits of elements between atomic numbers 20 and 29. In this case transitions from the K or 1S level to vacancies in the 3d level are not allowed according to the selection rules; nevertheless, at 29 Cu, where the 3d level becomes complete, there is a sharp "break" in the modified Moseley curve. It is also reasonable to expect slight deviations from the average curve wherever filling of the electronic subshells is somewhat irregular, although such deviations appear to be generally less than the spread in experimental points so that it is not clearly evident whether they occur at all.

The modified Moseley diagrams have been used to determine those measurements which yield values of $\sqrt{\tilde{\nu}}$ most nearly conforming to a smooth curve of the form expected, based on the assumptions mentioned above. The majority of recommended wavelengths appearing in the tables of section VI are those for which $\sqrt{\tilde{\nu}}$ satisfies this condition. In a number of instances the curve passes between two or more values, and in such cases the recommended wavelength has been taken directly from the curve. This in essence amounts to taking a weighted average, the weighting being determined to a large extent by adjacent values. Where no measurements have been

found in the literature, or those available differ quite significantly from what we have determined to be the most probable curve, interpolated values have been recommended.

Although most of the measurements reviewed have been evaluated on the basis of modified Moseley diagrams, there are a few for which there was insufficient data available for constructing such diagrams. For these cases, the recommended wavelengths are simply the published values considered most accurate, changed only in that they have been rounded off to reflect our estimate of accuracy, as are all of the recommended wavelengths. The absorption limits in this category are the M limits for elements of atomic number below 73 and all limits for elements of atomic number greater than 83.

The inert gases constitute a somewhat special case in that the absorbers were gaseous for all measurements evaluated and the absorption limit energies, hence $\sqrt{\tilde{\nu}}$ values, should be slightly different for the solid state. For this reason, the true modified Moseley curves for measurements carried out with solid absorbers are not expected to pass directly through the points corresponding to inert gases. The difference however, should be small[9]

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[9] Soules and Shaw (reference 106) compared the K absorption edge curves for solid and gaseous argon and krypton and found that the absorption limits differed by roughly 1 ev and 4 ev respectively, the lower energies, or longer wavelengths, occurring for the gaseous absorbers.

and the diagrams have assisted to some extent in evaluating these measurements also.

In the preceding paragraphs, all of the basic methods used to evaluate the absorption limit measurements have been described and each of the recommended wavelengths in the tables carries a superscript indicating that particular method used in its determination[10]. The remainder of this section is devoted primarily to explaining the procedures employed in determining the most probable form for the individual modified Moseley curves.

K Absorption Limits. The first diagram in appendix A covers the K limits from 10 Ne to 17 Cl. Only a few investigations have been made in this region and several of those are quite old. The most recent measurement in this group is Roualt's for 13 Al, which was published in 1957 and is considered significantly more accurate than the remaining measurements. At 10 Ne and 11 Na the curve is of practically no value, since any reasonable measurements could be made to lie on a smooth curve here, and only a single measurement is available in each case. Points between 12 Mg and 17 Cl are few, and are best fitted by a nearly straight line keyed to Roualt's 1957 measurement for 13 Al. Between 16 S and 17 Cl the slope

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[10] The system of superscripts used is described in section V.

decreases slightly; however, this is considered reasonable, since the only measurement available for 17 Cl was carried out with a gaseous absorber. As mentioned previously, Soules and Shaw (106) found that the K absorption limits for 18 A and 36 Kr were both of longer wavelength (smaller value for $\sqrt{\tilde{\nu}}$) for a gaseous absorber than for a solid, so it is reasonable to assume that this is the case here and that the limit of a solid Cl absorber would fall more in line with the limits of lower Z.

An abundance of measurements are available for elements between 18 A and 35 Br; since there are none in this group which stand out as being of particularly greater accuracy than the rest, the curve here is simply a best fit to the more recent experimental points. At 20 Ca there is a definite "break" in the curve, which may be accounted for by the fact that the 4s level is filled at this point. Since this leaves only three points between 18A and 20 Ca, the curve is of somewhat marginal value for evaluating these three limits. At 21 Sc, the only measurement available in the literature is Fricke's (37), published in 1920 and an interpolated value is recommended. From 22 Ti to 29 Cu, heavy reliance has been placed on Sanner's 1941 measurements. At 29 Cu the 3d level is filled and there is again a definite "break" in the curve and the recommended value for this limit has in

essence been determined by extrapolation of the curve from 30 Zn to 35 Br.

Between 36 Kr and 53 I, the modified Moseley diagram is much the same as that between 18 A and 35 Br. Again there are no measurements of outstanding accuracy and the curve is drawn to fit the more recent measurements. Several of these were carried out using compounds; however, the difference between the absorption limits of compound and pure absorbers is probably less than the precision of measurements in this region. At 46 Pd, the 4d level is filled and as for 29 Cu, the recommended value is based on an extrapolation of the curve from 47 Ag to 50 Sn.

Recent measurements of the absorption limits for elements 55 Cs to 72 Hf have been carried out exclusively with bent crystal instruments, using absorbers in various compound forms. Because of this, the curve which best fits these points is primarily of value as an indication of relative accuracy and as a means of interpolating for 69 Tm, where the only available measurement is too old to be considered reliable.

Only a few measurements have been made of the K absorption limits of elements 73 Ta to 83 Bi; however, several of these are quite recent and considered to be of significantly high accuracy. In particular these are the measurements by Beckman, Bergvall and Axelsson

(6,8) for 74 W and 79 Au, and that of Bearden (4) for 82 Pb. The curve for this diagram is keyed to these three points; the shape, however, was largely determined from values calculated in the manner described above. These calculated points are an average of the results obtained from a combination of the L_{II} and L_{III} absorption wave numbers with the K_{α_2} and K_{α_1}, emission line wave numbers.

L Absorption Limits. Very few measurements have been made of the L limits for elements of low atomic number; however, the modified Moseley diagrams have been useful in this region, particularly for obtaining interpolated values where measurements are unreliable, or non-existent.

For L_I, the first group includes elements from 30 Zn to 38 Sr. The first portion of the curve in this case has been determined from three measurements, namely those of 32 Ge (61), 33 As (93), and 34 Se (93). Since the L_I limits for 30 Zn and 31 Ga have never been measured, approximate values have been determined by extrapolation. At 36 Kr there appears to be a significant error in Brogren's 1948 measurement (9) and it has been discounted. The second portion of this curve was actually determined from the measurements for 37 Rb to 42 Mo, but only the points for 37 Rb and 38 Sr were included in the reproduction,

as the next diagram starts again with 36 Kr. This portion of the curve, as well as that for the next group of L_I limits up to 46 Pd has been determined from measurements conducted in 1926 by Coster and Mulder (31), using various compounds, and the recommended L_I absorption limit wavelengths interpolated from the curve in this region are only approximate values; however, they are probably better than the available measured values.

For L_{II} and L_{III} limits, measurements for the first group of elements are more recent and for the L_{III} limits at least, correspondingly more reliable. The L_{II} limits however are probably distorted by overlapping fine structure from the L_{III} edges. This effect has been noted by several investigators in the absorption spectra of low Z elements up to 53 I. (See references 76 and 93). The curves for the first group of elements from 26 Fe to 38 Sr have been drawn for both the L_{II} and L_{III} limits to fit the more recent measurements.

As already mentioned, the measurements of L_I limits available for elements from 37 Rb to 45 Rh are quite old and unreliable, and the curve in this region consists of two straight line segments from which interpolated values have been taken. The remaining measurements on this diagram (46 Pd to 48 Cd) include the results of more recent investigations and this portion of the curve

is a best fit to these measurements.

More recent measurements of most of the L_I and L_{III} limits are available for the elements 36 K to 48 Cd; however, the curve which has been drawn through these points is not smooth, nor of the same general form as the curves for most other groups.

The L_I, L_{II} and L_{III} curves for the group of elements from 44 Ru to 55 Cs are again a best fit to the more recent measurements. The same is true of the L_I, L_{II} and L_{III} curves for elements from 56 Ba to 72 Hf; however, in this case we have relied on the measurements published by Coster, Nishina and Wernor (32) in 1923 and by Nishina (75) in 1925 to determine the shape of portions of these curves where more recent measurements have not been made. The position of the curve was then determined by the few modern bent crystal measurements available, all of which were carried out using absorbers in oxide form. As for the L_I, L_{II} and L_{III} diagrams in the previous group, the L_I and L_{II} diagrams here have several unexplainable "breaks".

The L_I and L_{II} and L_{III} modified Moseley diagrams for elements 73 Ta to 83 Bi are divided into two groups, the first covering 73 Ta to 81 Tl and the second covering 76 Os to 83 Bi. In each case the curves have been drawn to best fit the more recent measurements. Key measurements

in this region considered significantly more accurate than the rest, are the L_I limit for 79 Au, measured by Mande (66) in 1956 and the L_I, L_{II} and L_{III} limits for 82 Pb measured by Ganson (38) in 1958.

M Absorption Limits. There have not been enough M absorption limit measurements carried out on elements below 73 Ta for construction of modified Moseley diagrams and those measurements which have been made are quite old. The recommended wavelengths for these limits which are included in the tables of section VI are simply an estimate of the best available measurements in the literature and must be considered as approximate only.

The accuracy, or perhaps more explicitly, the inaccuracy of the M absorption limits is graphically illustrated by the modified Moseley diagrams constructed for elements 73 Ta to 83 Bi. In order to assist in determining the most probable shape for these curves, values have been calculated from L absorption and emission data as described above. For the M_I and M_{II} limits, the calculated values are considered better than the available measured values. For M_{III} limits, there is relatively good agreement between the calculated and measured values and both have been used with about equal weight to determine the best curve. The measurement considered most a curate in this group is that by Mande (65) for 79 Au, published in 1957.

In the case of the M_{IV} and M_V limits, the disparity between measured and calculated values is too large to be explained on the basis of the estimated experimental error, or it would seem, on the basis of different final states for the L absorption limits used in the calculation and the actual final states for the M_{IV} and M_V absorption limits. The procedures followed in determining the curves for these two cases was to first draw a curve through the calculated points for the purpose of establishing the most probable shape. The resulting curve was then moved up so that it passed through the point corresponding to the measurement for 79 Au by Mande (65) which is considered as the most reliable measurement available in this region. Recommended wavelengths were then determined by interpolation from this curve.

IV. Discussion of Accuracy

Because the true meaning of an absorption limit (as defined in Section II) is not absolutely known, recent precise measurements lose some of their significance; nevertheless, this is the only point on absorption spectra which has been consistently measured by many investigators for the various elements. For this reason, these measurements provide at least a means of comparing the relative energy values of elements having similar electronic structure. Furthermore, even though the exact meaning is somewhat uncertain, it seems safe to assume that the absorption limit is, for most practical purposes, a measure of the minimum energy for photoelectric absorption from the initial level. Although the inflection point of the absorption coefficient versus wavelength curves is of greater significance theoretically, little appears to be lost in approximating it by the corresponding inflection point on a photometric curve. The difference is small compared to the precision of the majority of measurements and no distinction has been made in the evaluating; in fact, no systematic difference could be seen on the modified Moseley diagrams. This difference is investigated in some detail in appendix B.

With regard to accuracy of the recommended absorption limit wavelengths, our primary concern is actually not the exact interpretation, but the experimental error involved, or, in other words, how accurately these values represent the longest wavelength inflection point of the true absorption curve. In this sense, the factors which are of interest are the precision of the measurements and the effects which distort the true absorption curve, such as the "thickness Effect".

The latter have been discussed in section II, but as noted there, not very much can be said concerning the magnitude of such distortions for the majority of measured limits. On the other hand however, it is believed that the method of using modified Moseley diagrams to evaluate the experimental results provides the best means of averaging out much of the experimental error, particularly for those cases where a large number of measurements have been made of a particular limit for a group of elements. Such cases generally involve several different types of spectrometers, various crystals and above all different investigators.

The general criterea used to estimate the accuracy of recommended values were essentially the smoothness of the Moseley curves and the scatter of points. On this basis, we have estimated the probable uncertainty

by considering the different ways in which the curves might have reasonably been drawn and then have taken half of the total deviation considered possible in terms of wavelength. The fractional error in wavelength is, of course, twice the fractional error in $\sqrt{\tilde{\nu}}$.

V. Explanation of the Tables

The tables of section VI are set up such that the 1st four columns provide a brief summary for each element of all recent measurements made of K, L and M absorption limits, including reference, wavelength measured, type of spectrometer used, type of registration, and date the reference was published, plus other pertinent facts. In the remaining four columns are the recommended wavelength, the inverse of the recommended wavelength or wave number, the square root of this wave number and the energy corresponding to each recommended wavelength[11].

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[11] The conversion factor used for calculating quantum energies from the recommended wavelengths was 12,373.0 kev - XU taken from references 114,(h,e, and e) and 115 ($\lambda_g/\lambda_s = 1.00203$).

The arrangement of the tables is as follows:

Column	Heading	Contains
1st	Disc	Designation of the X-ray level.
2nd	Ref	Number of the reference as listed in the bibliography, in which the measurement is reported. Calculated values are indicated by "calc."
3rd	λ	Measured wavelength as published in the listed reference. Absolute measurements are indicated by an asterisk, all others are measured relative to reference lines. If the value has been corrected, the corrected value is given in parenthesis below the published value. Calculated values are enclosed in square brackets.
4th	Remarks	Type of spectrometer, type of registration, date of publication and the compound or state used as absorber if not the pure element in its solid state. For calculated values, the X-ray designation of

Column	Heading	Contains
		absorption limits and emission lines used are listed. In a few very old papers, the measurement was made at the peak of absorption and half the slit width added to obtain published value. This is indicated by "Abs. Pk."
5th	λ_r	The recommended absorption limit wavelength (XU).
6th	$\tilde{\nu} \times 10^7$	Wave number (XU^{-1}) times 10^7 calculated from the recommended wavelength
7th	$\sqrt{\tilde{\nu}} \times 10^5$	Square root of the wave number ($XU^{-\frac{1}{2}}$) times 10^5
8th	kev	Quantum energy (kev) corresponding to the recommended wavelength

The estimated accuracy of recommended wavelengths, and of quantities calculated using these values, is indicated approximately by the last digit of each numerical value. Those values for which the estimated uncertainty is a few parts in the last digit are written in the normal manner. When the uncertainty is estimated

as being from 10 to 20 parts in the last two digits, the last digit has been subscripted. In a few instances the last two digits are both subscripted. This has been done to avoid introducing additional powers of ten in the tables and in these cases the last digit is considered meaningless.

The superscripts preceding each of the recommended wavelengths indicates the method used in determining it as follows:

a - Based on a single experimental measurement which is considered significantly better than any others for the particular absorption edge and is among the best in the wavelength region involved. Such values, when available, play a decisive role in determining the position of the modified Moseley curve.

b - Based on the single experimental value which lies closest to the modified Moseley curve.

c - Value given by modified Moseley curve, which passes between two or more experimental points for the element concerned; hence it may alternately be regarded as a weighted means of measured values.

d - Value based on a single experimental value or an average of experimental values where the Moseley curve was unavailable or inconclusive.

† - Interpolated values where measurements for adjacent elements are reasonably good and the Moseley

curves well determined.

††- Interpolated values where the form of the Moseley curves is more uncertain. These wavelengths are approximations at best, but better than any measurements available.

Key to abbreviations:

SC	Single crystal spectrometer of the Siegbahn type.
DC	Double crystal spectrometer.
BCR	Bent crystal spectrometer of the reflection type.
BCT	Bent crystal spectrometer of the transmission type.
BCR^1	Spectrograph described in reference 102. It differs from the bent crystal instruments used by most investigators in that the axis of the cylindrically bent crystal lies in the plane of dispersion; whereas, in the usual arrangement, the axis of symmetry is normal to the plane of dispersion of the x-ray spectrum.
TS	Tube spectrograph.
TS^2	Diffractometer used as tube spectrograph.

FCT	Spectrometer used by Mack and Cork (62) employing transmission through a flat crystal.
PH	Photographic registration.
IC	X-ray spectra registered by means of an ionization chamber type of detector (i.e. ionization chamber, proportional counter or Geiger counter).
Sc.C.	X-ray spectra registered with scintillation counter.
Abs.Pk.	Measurement made at the maximum of absorption just preceding the edge. In most cases the wavelengths measured in this manner were "corrected" for half the slit width in the mistaken belief which was held by some of the early investigators that the breadth of the edge was due to the geometry of the spectrometer.

VI. Tables

10 Ne

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	9	14272.2	BCR - IC - 48 Gas				
				$^d14272._2$	700.66	837.06	0.8669_3

11 Na

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	88	11545.0	BCR - Ph - 44				
				$^d11545$	866.2	930.7_0	1.0717

12 Mg

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	93	9492.5	BCR - Ph - 35				
				[b]9492.5	1053.5	1026.4	1.3034_5

13 Al

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	87	7931.66	BCR - IC - 57				
	93	7935.1	BCR - Ph - 35				
				[a]7931.6_6	1260.77	1122.84	1.55995

14 Si

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	3	6715.2	SC - Ph - 47				
				†6723.8	1487.2	1219.5_3	1.8402

15 P

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	53	5774.9	SC - Ph - 23				
				†5771.7	1732.5_9	1316.28	2.1437

16 S

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	53 10	5008.8 5008.1	SC - Ph - 23 SC - Ph - 44				
				^{b}5008.1	1997.4	1413.3	2.4706

17 Cl

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	57	4388.0	SC - Ph - 44 Cl_2, Gas				
				^{b}4388.0	2278.9_4	1509.62	2.8197

18 A

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	9	3862.8	BCR - IC - 48 Gas				
	58	3862.88	SC - Ph - 44 Gas				
				[d]3862.8_8	2588.7_4	1608.96	3.2030

19 K

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	96	3429.52	BCR - Ph - 41				
	82	3428.8 (3429.2)	DC - IC - 45				
	54	3431.0 (3429.8)	SC - Ph - 24				
				[c]3429.4	2915.9_6	1707.62	3.6079_2

20 Ca

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	96	3063.97	BCR - Ph - 41				
	48	3063.9	SC - Ph - 30				
	54	3064.3	SC - Ph - 24				
				^{c}3064.0	3263.7	1806.5_8	4.0382

21 Sc

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	37	2751.7	SC - Ph - 20 Sulfate				
				†2756	3628	$1904._7$	4.489

22 Ti

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	96 5c	2492.27 2491.2	PCR - Ph - 41 SC - Ph - 25				
				$^b2492.2_7$	4012.4	2003.1_0	4.9646

23 Va

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	96	2264.45	BCR - Ph - 41				
	55	2263.0	SC - Ph - 25				
				$^{b}2264.4_5$	4416.1	2101.4_4	5.4640

24 Cr

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	96	2065.95	BCR - Ph - 41				
	48	2066.1	SC - Ph - 30				
	55	2066.3	SC - Ph - 25				
				$^{b}2065.9_5$	4840.4	2200.0_9	5.9890

25 Mn

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	96	1892.54	BCR - Ph - 41				
	48	1891.3	SC - Ph - 30				
	55	1892.1	SC - Ph - 25				
				^{b}1892.5$_4$	5283.9	2298.6$_8$	6.5377

26 Fe

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K .	96	1739.83	BCR - Ph - 41				
	7	*1739.9	DC - IC - 39				
	59	1739.3	SC - Ph - 28				
	55	1740.5	SC - Ph - 25				
				^{c}1739.87	5747.55$_6$	2397.40	7.1114

26 Fe

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
L_{II}	102	17200.4 (17165.7)	BCR[1] - Ph - 57				
				$^b1716_6$	582.5	763.2	0.7207
L_{III}	102	17524.7 (17489.4)	BCR[1] - Ph - 57				
				$^b1748_9$	571.8	756.2	0.7075

27 Co

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	96	1604.87	BCR - Ph - 41				
	7	*1604.9	DC - IC - 39				
	48	1604.3	SC - Ph - 30				
	97	1604.75	BCT - Ph - 57				
				$^b1604.8_7$	6231.0	2496.2_0	7.709_7
L_{II}	102	15623.5 (15589)	BCR^1- Ph - 57				
				$^b1558_9$	641.4	800.9	0.7937
L_{III}	102	15920.3 (15886)	BCR^1- Ph - 57				
				$^b1588_6$	629.5	793.4	0.7789

28 Ni

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	96 7 98 48 56	1485.02 *1485.2 1483.8 1484.6 1485.01	BCR - Ph - 41 DC - IC - 39 BCT - Ph - 55 SC - Ph - 30 SC - Ph - 30				
				$^{b}1485.0_{2}$	6733.9	2595.0	8.331_{9}
L_{II}	102	14240.5 (14211.8)	BCR^{1}- Ph - 57				
				$^{b}1421_{2}$	703.7	838.9	0.8706
L_{III}	102	14524.3 (14495.0)	BCR^{1}- Ph - 57				
				$^{b}1449_{5}$	689.9	830.6	0.8537

29 Cu

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	96	1377.65	BCR - Ph - 41				
	56	1378.08	SC - Ph - 30				
	48	1377.8	SC - Ph - 30				
	7	*1377.7	DC$_1$ - IC - 39				
	101	1378.3	TS^1 - IC - 58				
	19	1377.98	BCT - Ph - 35				
				$^{c}1377.7_{7}$	7258.1	2694.1	8.9804
L_{II}	102	13014.5 (12987)	BCR^1 - Ph - 57				
	21	13.012 Å (12985)	BCR - Ph - 53				
				$^{c}1298_{6}$	770.1	877.5	0.952_{8}
L_{III}	102	13286.2 (13259.4)	BCR^1 - Ph - 57				
	21	13.287 Å (13260)	BCR - Ph - 53				
				$^{b}13260$	754.1	868.3_{8}	0.9330

30 Zn

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	7	*1280.7	DC - IC - 39				
	39	1280.5	SC - Ph - 31				
	48	1280.8	SC - Ph - 30				
	56	1280.60	SC - Ph - 30				
				$^{b}1280.7$	7808	2794.3	9.661
L_I	-	-	-				
				$^{\pi}103_{33}$	968	984	1.19_8
L_{II}	93	11837	BCR - Ph - 35				
				$^{b}1183_7$	844.8	919.1	1.045_3
L_{III}	93	12106.4	BCR - Ph - 35				
				$^{b}12106$	826.0	908.8_7	1.0220

31 Ga

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	23 7 73 48	1193.26 *1193.4 1192.5 1192.9	BCT - Ph - 40 DC - IC - 39 SC - IC - 36 SC - Ph - 30				
				$^{c}1193.3$	$8380._{1}$	2894.8	10.368
L_I	-	-	-				
				$^{\#}949_{7}$	1053	$1025._{7}$	1.303
L_{II}	-	-	-				
				$^{\dagger}1080_{6}$	$925._{4}$	962.0	1.145_{0}
L_{III}	60	11.099 Å (11077)	BCR - Ph - 56				
				$^{b}11077$	902.7_{7}	950.14	1.1170

32 Ge

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	23 7 35	1114.27 *1114.3 1114.6	BCT - Ph - 40 DC - IC - 39 SC - Ph - 20				
				$^{b}1114.2_7$	$8974._5$	2995.7_4	11.104_1
L_I	61	8.773 Å (8755)	BCR - Ph - 59				
				$^{b}8755$	1142.2	1068.7	1.4113
L_{II}	60	9.923 Å (9903)	BCR - Ph - 56				
				$^{b}9903$	1009.8	1004.9	1.2494
L_{III}	60	10.187 Å (10166)	BCR - Ph - 56				
				$^{b}10166$	983.7	991.8	1.2171

33 As

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	23 39 51	1042.86 1042.49 1042.63 (1043.0)	BCT - Ph - 40 SC - Ph - 31 TS - Ph - 25				
				$^{b}1042.8_{6}$	$9589._{0}$	3096.6	11.864
L_I	93	8090.4	BCR - Ph - 35				
				$^{b}8090$	1236.0	1111.8	1.5294
L_{II}	93	9106	BCR - Ph - 35				
				$^{b}9106$	1098.2	1047.9	1.3588
L_{III}	93	9348.2	PCR - Ph - 35				
				$^{b}9348$	1069.8	1034.3	1.3236

34 Se

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	33	977.67	DC - Sc.C - 59				
	23	977.80	BCT - Ph - 40				
	48	977.8	SC - Ph - 30				
	43	977.9	SC - Ph - 29				
	51	977.63	TS - Ph - 25				
		(977.76)					
				•977.71	10228.0	3198.12	12.655$_1$
L_I	93	7490.4	BCR - Ph - 35				
	112		BCR - IC - 58				
		7484.7	metallic				
		7486.9	vitreous				
				^{b}7490	1335.0	1155.4	1.651$_9$
L_{II}	93	8389.7	BCR - Ph - 35				
				^{b}8390	1191.9	1091.8	1.4747
L_{III}	93	8628	BCR - Ph - 35				
				^{b}8628	1159.0	1076.6	1.4340

35 Br

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	39	918.04	SC - Ph - 31 NaBr	$^d918.0_4$	$10892._8$	3300.4	13.478
		918.51	Br$_2$ vapor	$^d918.5_1$	$10887._3$	3299.6	13.471
	51	918.09	TS^2 - Ph - 25 KBr	$^d918.1$	10892	3300.3	13.477
L_I			Interpolated	^{†6945}	$1440._0$	1200.0	1.781_6
L_{II}			relative to adjacent	^{†7737}	$1292._5$	1136.9	1.599_2
L_{III}			pure elements	^{†7967}	$1255._1$	1120.3	1.553_0

36 Kr

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	9	863.73	BCR - IC - 48 Gas				
	39	863.72	SC - Ph - 31 Gas				
				$^{b}863.73$	11577.7	3402.60	14.325_1
L_I	9	6498.1	BCR - IC - 48 Gas				
				$^{ff}6459$	$1548._3$	1244.3	1.915_6
L_{II}	9	7153.4	BCR - IC - 48 Gas				
				$^{b}7153._4$	1397.9	1182.3_4	1.7297
L_{III}	9	7376.7	BCR - IC - 48 Gas				
				$^{b}7376._7$	1355.6	1164.3_1	1.6773

37 Rb

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	44	813.85	BCT - Ph - 34 Sulfate				
	51	814.10	TS - Ph - 25 Sulfate				
				sulfate $^{b}813.8_5$	12287	3505.3	15.203
L_I	31	5985.4	SC - Ph - 26 **Nitrate**				
				‡5996	$1667._8$	1291.4	2.063_5
L_{II}	-	-	-	‡6629	$1508._6$	1228.2	1.866_5
L_{III}	31	6841.3	SC - Ph - 26 Nitrate				
				‡6846	$1460._6$	1208.5	1.807_3

38 Sr

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	51	768.37	TS - Ph - 25 Chloride				
	44	768.14	BCT - Ph - 34 Oxide	oxide			
				$^{b}768.1_4$	13018	3608.1	16.108
L_I	31	5571.3	SC - Ph - 26 Nitrate				
				π5580	$1792._1$	1338.7	2.217_3
L_{II}	31	6162.1	SC - Ph - 26 Nitrate				
	93	6159.9	BCR - Ph - 35 Oxide	oxide			
				$^{b}6160$	1623.4	1274.1	2.008_6
L_{III}	31	6362.0	SC - Ph - 26 Nitrate				
	93	6373.9	BCR - Ph - 35 Oxide	oxide			
				$^{b}6374$	1568.9	1252.5	1.941_2

39 Y

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	44	726.15	BCT - Ph - 34 Oxide	oxide			
				$^{b}726.1_5$	13771	$3711._0$	17.039
L_I	31	5221.6	SC - Ph - 26 Sulfate				
				‡5206	$1920._9$	1385.9	2.377
L_{II}	31	5737.3	SC - Ph - 26 Sulfate				
	93	5743.5	BCR - Ph - 35 Oxide	oxide			
				$^{b}5744$	1741.2	1319.6	2.154_1
L_{III}	31	5944.4	SC - Ph - 26 Sulfate				
	93	5949.8	BCR - Ph - 35 Oxide	oxide			
				$^{b}5950$	1680.7	1296.4	2.079_5

40 Zr

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	46	687.39	BCT - Ph - 54				
	44	687.38	BCT - Ph - 34				
	85	*687.43	DC - IC - 33				
				^{c}687.40	14547.6	3814.1_3	17.999_7
L_I	31	4857.4	SC - **Ph** - 26 **Chloride**				
				‡4869	2053_9	1433.1	2.541
L_{II}	31	5365.9	SC - Ph - 26 Chloride				
	93	5367.0	BCR - Ph - 35				
				^{b}5367	1863.2	1365.0	2.305
L_{III}	31	5561.0	SC - Ph - 26 Chloride				
	93	5571.6	BCR - Ph - 35				
				^{c}5567	$1796._3$	1340.3	2.223

41 Nb

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	44 85	651.59 *651.71	BCT - Ph - 34 DC - IC - 33				
				^{c}651.63	15346.1	3917.4_1	18.987_8
L_I	31	4571.7	SC - Ph - 26 K_2NbF_7				
				π4563	$2191._5$	1480.8	2.712
L_{II}	-	-	-	π5029	$1988._5$	1410.1	2.460
L_{III}	31	5212.1	SC - Ph - 26 K_2NbF_7				
				π5221	$1915._3$	1384.0	2.370

42 Mo

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	40	618.52	BCT - Ph - 35				
	44	618.48	BCT - Ph - 34				
	85	*618.51	DC - IC - 33				
	51	618.48	TS - Ph - 25				
				^{c}618.50	$16168._1$	4020.9_6	20.005
L_I	31	4289.7	SC - Ph - 26 $(NH_4)Mo_7O_{24} \cdot 4H_2O$				
				#4285	$2333._7$	1527.2	2.888
L_{II}	31	4712.0	SC - Ph - 26 $(NH_4)Mo_7O_{24} \cdot 4H_2O$				
	93	4708.5	BCR - Ph - 35				
				^{b}4709	$2123._6$	1457.3	2.628
L_{III}	31	4904.2	SC - Ph - 26 $(NH_4)Mo_7O_{24} \cdot 4H_2O$				
	93	4902.6	BCR - Ph - 35				
				^{b}4903	$2039._6$	1428.1	2.524

43 Te

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	-	-	-				
				†587.84	17011.4	4124.4_9	21.048
L_I	-	-	-				
				#4045	$2472._2$	1572.6	3.059
L_{II}	-	-	-				
				#4427	$2258._9$	1503.0	2.795
L_{III}	-	-	-				
				#4620	$2164._7$	1471.3	2.678

44 Ru

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	44 85	559.34 *559.35	BCT - Ph - 34 DC - IC - 33				
				^{b}559.35	$17877._9$	4228.2_2	22.120
L_I	-	-	-				
				††3824	$2615._1$	1617.1	3.236
L_{II}	31 93	4164.8 4171.1	SC - Ph - 26 BCR - Ph - 35				
				$^{b}4171._1$	2397.5	1548.4	2.966_4
L_{III}	31 93	4357.7 4360.1	SC - Ph - 26 BCR - Ph - 35				
				$^{b}4360._1$	2293.5	1514.4	2.837_8

45 Rh

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	40 44 85	532.70 532.88 *532.82	BCT - Ph - 35 BCT - Ph - 34 DC - IC - 33				
				[c]532.84	$18767._4$	4332.1_0	23.221
L_I	31	3620.8	SC - Ph - 26 Rh_2Cl_2 & $NaRhCl_6$				
				[‡]362_1	2762	1662	3.41_7
L_{II}	31	3931.5	SC - Ph - 26 Rh_2Cl_2 & $NaRhCl_6$				
	93	3934.3	BCR - Ph - 35				
				[b]$3934._3$	2541.8	1594.3	3.144_9
L_{III}	31	4118.4	SC - Ph - 26 Rh_2Cl_2 & $NaRhCl_6$				
	93	4121.3	BCR - Ph - 35				
				[b]$4121._3$	2426.4	1557.7	3.002_2

46 Pd

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	64 44 85 51	508.26 508.12 *508.06 507.95 (508.04)	BCT - Ph - 57 BCT - Ph - 34 DC - IC - 33 TS - Ph - 25				
				^{e}508.15	19679.$_2$	4436.1$_2$	24.349
L_I	93	3427.8	BCR - Ph - 35				
				^{b}3427.$_8$	2917.$_3$	1708.0	3.609$_6$
L_{II}	93	3716.3	BCR - Ph - 35				
				^{b}3716.3	2690.8	1640.3$_8$	3.329$_4$
L_{III}	93	3900.2	BXR - Ph - 35				
				^{b}3900.2	2564.0	1601.2$_4$	3.172$_4$

47 Ag

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	44	484.84	BCT - Ph - 34				
			Bromide				
	85	*484.88	DC - IC - 33				
				^{b}484.88	$20623._6$	4541.3_2	25.518
L_I	31	3244.8	SC - Ph - 26				
			Bromide				
	76	3249.8	BCR - IC - 61				
				^{b}3249.8	3077.1	1754.1_7	3.8073
L_{II}	31	3506.2	SC - Ph - 26				
			Bromide				
	76	3509.3	BCR - IC - 61				
				^{b}3509.3	2849.6	1688.0_6	3.5258
L_{III}	31	3693.0	SC - Ph - 26				
			Bromide				
	76	3692.1	BCR - IC - 61				
				^{b}3692.1	2708.5	1645.7_4	3.3512

48 Cd

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	44	463.15	BCT - Ph - 34				
	85	*463.07	DC - IC - 33				
	51	463.13	TS - Ph - 25				
				[c]463.11	$21593._1$	4646.8_4	26.717
L_I	93	3078.3	BCR - Ph - 35				
	77	3078.6	BCR - IC - 61				
				[b]3078.6	3248.2	1802.2_8	4.0190
L_{II}	93	3319.0	BCR - Ph - 35				
	77	3318.8	BCR - IC - 61				
				[b]3318.8	3013.1	1735.8_4	3.7282
L_{III}	93	3496.7	BCR - Ph-35				
	77	3497.5	BCR - IC - 61				
				[b]3497.5	2859.5	1691.0_1	3.5377

49 In

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	51	442.98 (442.70)	TS - Ph - 25				
				†442.79	22584	4752.2	27.943
L_I	93	2919.8	BCR - Ph - 35				
	77	2919.9	BCR - IC - 61				
				^{b}2919.9	3424.8	1850.6_2	4.2375
L_{II}	93	3140.6	BCR - Ph - 35				
	77	3141.0	BCR - IC - 61				
				^{c}3140.8	3183.9	1784.3_5	3.9394
L_{III}	93	3317.7	BCR - Ph - 35				
	77	3316.8	BCR - IC - 61				
				^{b}3316.8	3015.0	1736.3_6	3.7304

50 Sn

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	44	423.82	BCT - Ph - 34				
	85	*423.76	DC - IC - 33				
	51	423.94	TS - Ph - 25				
		(423.80)					
				^{c}423.79	23596	4857.6	29.196
L_I	93	2771.5	BCR - Ph - 35				
	77	2771.2	BCR - IC - 61				
				^{b}2771.2	3608.5	1899.6_2	4.464_5
L_{II}	93	2976.3	BCR - Ph - 35				
	77	2976.2	BCR - IC - 61				
				^{b}2976.2	3360.0	1833.0_3	4.1573
L_{III}	93	3149.5	BCR - Ph - 35				
	77	3149.0	BCR - IC - 61				
				^{b}3149.5	3175.1	1781.8_8	3.9286

51 Sb

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	74	405.88	BCT - Ph - 51				
	85	*405.81	DC - IC - 33				
				^{c}405.84	24640	4963.9	30.487
L_I	77	2633.3	BCR - IC - 61				
	93	2634.1	BCR - Ph - 35				
	28	2631.7	SC - Ph - 27				
		(2632.3)	Abs. Pk.				
				^{b}2633.3	3797.5	1948.7_2	4.698_7
L_{II}	77	2823.1	BCR - IC - 61				
	93	2824.0	BCR - Ph - 35				
	28	2821.9	SC - Ph - 27				
		(2822.5)	Abs. Pk.				
				^{b}2824.0	3541.1	1881.7_8	4.3814
L_{III}	77	2994.2	BCR - IC - 61				
	93	2993.9	BCR - Ph - 35				
	28	2990.7	SC - Ph - 27				
		(2991.2)	Abs. Pk.				
				^{b}2994.2	3339.8	1827.5_1	4.1323

52 Te

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	85	*388.93	DC - IC - 33				
	51	389.26	TS - Ph - 25				
				$^b388.93$	25712	5070.7	31.813
L_I	77	2504.7	BCR - IC - 61				
	93	2505.4	BCR - Ph - 35				
	28	2503.9	SC - Ph - 27				
		(2504.2)	Abs. Pk.				
				$^b2504.7$	3992.5	1998.1_2	4.939_9
L_{II}	77	2682.5	BCR - IC - 61				
	93	2682.0	BCR - Ph - 35				
	28	2679.3	SC - Ph - 27				
		(2679.6)	Abs. Pk.				
				$^e2682.2$	3728.3	1930.8_8	4.613_0
L_{III}	77	2849.6	BCR - IC - 61				
	93	2849.6	BCR - Ph - 35				
	28	2845.7	SC - Ph - 27				
		(2845.8)	Abs. Pk.				
				$^b2849.6$	3509.3	1873.3_0	4.3420

53 I

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	85	*373.04	DC - IC - 33				
				[b]373.04	26807	5177.5	33.168
L_I	28	2383.9 (2384.0)	SC - Ph - 27 Abs. Pk.				
	100	2402	SC - Ph - 24				
				†2383.1	4196	2048.5	5.192
L_{II}	28	2547.5 (2547.2)	SC - Ph - 27 Abs. Pk.				
	100	2548	SC - Ph - 24				
				†2548.4	3924	1980.9	4.855
L_{III}	28	2713.9 (2712.7)	SC - Ph - 27 Abs. Pk.				
	100	2711	SC - Ph - 24				
				†2714.0	3684	1919.5	4.559

54 Xe

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	42	357.77	BCR - Ph - 33 Gas				
				$^{d}357.77$	27951	5286.9	34.58_4
L_I	9	2269.0	BCR - IC - 48 Gas				
	39	2269.1	SC - Ph - 31 Gas				
				$^{b}2269.0$	4407.2	2099.3_4	5.453_1
L_{II}	9	2424.3	BCR - IC - 48 Gas				
	39	2424.1	SC - Ph - 31 Gas				
				$^{c}2424.2$	4125.1	2031.0_2	5.104_0
L_{III}	9	2587.2	BCR - IC - 48 Gas				
	39	2587.2	SC - Ph - 31 Gas				
				$^{b}2587.2$	3865.2	1966.0_0	4.782_4

55 Cs

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^6$	kev
K	12	343.80	BCT - Ph - 55 KSO_4Cs_2				
	51	*344.04	TS - Ph - 25 Cesiumalun				
				K SO_4Cs_2 ^{b}343.80	29087	5393.2	35.989
L_I	47	2162.8	BCT - Ph - 34 Sulfate				
				Sulfate $^b2162._8$	4624	2150.3	5.721
L_{II}	47	2309.1	BCT - Ph - 34 Sulfate				
				Sulfate ^{b}2309.1	$4330._7$	2081.0	5.358_4
L_{III}	47	2468.9	BCT - Ph - 34 Sulfate				
				Sulfate ^{b}2468.9	$4050._4$	2012.6	5.011_5

56 Ba

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	12	330.35	BCT - Ph - 55 KBaO				
	51	*330.70	TS - Ph - 25 Chloride				
				KBaO ^{a}330.35	30271	5501.9	37.454
L_I	47	2063.5	BCT - Ph - 34 Oxide				
				Oxide ^{b}2063.$_5$	4846	2201.$_4$	5.996
L_{II}	47	2200.2	BCT - Ph - 34 Oxide				
				Oxide ^{b}2200.2	4545.$_0$	2131.9	5.623$_6$
L_{III}	47	2358.0	BCT - Ph - 34 Oxide				
				Oxide ^{b}2358.0	4240.$_9$	2059.3	5.247$_2$

57 La

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	51	*318.14	TS - Ph - 25 $La(NO_3)_3 \cdot 6H_2O$				
	86	317.78	BCT - Ph - 39 Oxalate	Oxalate			
				$^b317.7_8$	3146_8	$5609._7$	38.93_6
L_I	32	1968.9 (1969.1)	SC - Ph - 23 Salt - Abs.Pk.				
				††1974	5066	2251	6.26_8
L_{II}	32	2098.9 (2099.1)	SC - Ph - 23 Salt - Abs.Pk.				
				††2101	4760	$2181._7$	5.88_9
L_{III}	32	2253.7 (2253.9)	SC - Ph - 23 Salt - Abs.Pk.				
				††2256	4432	$2105._1$	5.48_3

58 Ce

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^1$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	51	*306.26	TS - Ph - 25 Sulfate				
	86	305.85	RCT - Ph - 39 Carbonate				
				Carbonate $^{b}305.8_5$	3269_6	$5718._0$	40.45_4
L_I	32	1885.6 (1885.8)	SC - Ph - 23 Salt - Abs. Pk.				
				$^{\dagger\dagger}1890$	5291	$2300._2$	6.54_7
L_{II}	32	2006.7 (2006.9)	SC - Ph - 23 Salt - Abs. Pk,				
				$^{\dagger\dagger}2008$	4980	$2231._6$	6.16_2
L_{III}	32	2159.7 (2159.8)	SC - Ph - 23 Salt - Abs. Pk.				
				$^{\dagger\dagger}2161$	4626	$2150._9$	5.72_4

59 Pr

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	86	294.57	BCT - Ph - 39 Oxalate	Oxalate $^{b}294.5_7$	3394_8	5826.5	42.00
L_I	75	1807.1 (1807.3)	SC - Ph - 25 Sulfate-Abs.Pk.	$^{\#}1811$	5521	2349.7	6.83_5
L_{II}	75	1920.1 (1920.3)	SC - Ph - 25 Sulfate-Abs.Pk.	$^{\#}1921$	5206	2281.6	6.44_1
L_{III}	75	2072.8 (2073.0)	SC - Ph - 25 Sulfate-Abs.Pk.	$^{\#}2074.8$	4820	2195.5	5.96_4

59 Pr

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
M_{IV}	104	13095	BCR - Ph - 52 Oxide	Oxide $^{d}1309_5$	763.6	873.9	0.944_9
M_V	104	13366	BCR - Ph - 52 Oxide	Oxide $^{d}1336_6$	748.2	865.0	0.925_7

60 Nd

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu}\times10^7$	$\sqrt{\tilde{\nu}}\times10^5$	kev
K	51	*284.58	TS - Ph - 25 Sulfate				
	86	283.94	BCT - Ph - 39 Oxalate				
				Oxalate $^{b}283.9_4$	3521_9	$5934._5$	43.57
L_I	75	1731.7 (1731.8)	SC - Ph - 25 Sulfate-Abs.Pk.				
	13	1735.45	BCT - Ph - 55 Oxide				
				Oxide $^{a}1735.4$	$5762._4$	2400.5	7.130
L_{II}	75	1839.1 (1839.3)	SC - Ph - 25 Sulfate-Abs.Pk.				
	13	1840.16	BCT - Ph -55 Oxide				
				Oxide $^{a}1840.2$	$5434._2$	2331.1	6.723_7

60 Nd

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
L_{III}	75	1990.7	SC - Ph - 25				
		(1991.1)	Sulfate-Abs.Pk.				
	13	1992.62	BCT - Ph - 55 Oxide				
				Oxide $^a1992.6$	$5018._5$	2240.2	6.209_5
M_{IV}	104	12433	BCR - Ph - 52 Oxide				
				Oxide $^d1243_3$	804.3	896.8	0.973_4
M_V	104	12711	BCR - Ph - 52 Oxide				
				Oxide $^d1271_1$	786.7	887.0	0.973_4

61 Pm

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	-	-	-	Oxalate †273.7_4	3653_1	$6044._1$	45.20
L_I	-	-	-	Oxide †1664	6010	$2451._9$	7.44
L_{II}	-	-	-	Oxide †1764	5669	$2380._9$	7.01_4
L_{III}	-	-	-	Oxide †1915	5222	$2285._1$	6.46_1

62 Sn

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	86	264.09	BCT - Ph - 39 Oxalate				
				Oxalate $^{b}264.0_{9}$	3786_{6}	$6153._{5}$	46.85
L_I	75	1595.4	SC - Ph - 25 Sulfate-Abs.Pk.				
	13	1596.90	BCT - Ph - 55 Oxide				
				Oxide $^{a}1596.9$	$6262._{1}$	2502.4	7.748
L_{II}	75	1699.1 (1698.9)	SC - Ph - 25 Sulfate-Abs.Pk.				
	13	1691.79	BCT - Ph - 55 Oxide				
				Oxide $^{a}1691.8$	$5910._{9}$	2431.2	7.314

62 Sm

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
L_{III}	75	1840.8 (1840.9)	SC - Ph - 25 Sulfate-Abs.Pk.				
	13	1841.90	BCT - Ph - 55 Oxide				
				Oxide $^a1841.9$	$5429._2$	2330.1	6.717_5
M_{IV}	104	11262.6	BCR - Ph - 52 Oxide				
	88	11267.6	BCR - Ph - 45 Oxide				
				Oxide $^d1126_5$	$887._8$	942.2	1.098_4
M_V	104	11525.6	BCR - Ph - 52 Oxide				
	88	11531.1	BCR - Ph - 45 Oxide				
				Oxide $^d1152_8$	$867._5$	931.4	1.073_3

63 Eu

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	70	255.00	BCT - Ph - 43 Oxide				
				Oxide ^{b}255.00	39216	6262.2	48.52_2
L_I	75	1533.3	SC - Ph - 25 Sulfate-Abs.Pk.				
	90	1534.86	BCT - Ph - 53 Oxide				
				Oxide ^{b}1534.9	$6515._1$	2552.5	8.061
L_{II}	75	1622.8 (1622.6)	SC - Ph - 25 Sulfate-Abs.Pk.				
	90	1623.71	BCT - Ph - 53 Oxide				
				Oxide ^{b}1623.7	$6158._8$	2481.7	7.620

63 Eu

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
L_{III}	75	1771.7	SC - Ph - 25				
		(1771.8)	Sulfate-Abs.Pk.				
	90	1772.38	BCT - Ph - 53 Oxide				
				Oxide ^{b}1772.4	5642.$_1$	2375.3	6.981
M_{IV}	104	10689	BCR - Ph - 52 Oxide				
				Oxide ^{d}1068$_9$	935.$_5$	967.2	1.157$_5$
M_V	104	10990	BCR - Ph - 52 Oxide				
				Oxide ^{d}1099$_0$	909.$_9$	953.9	1.125$_8$

64 Gd

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	70	246.30	BCT - Ph - 43 Oxide				
				Oxide ^{b}246.30	40601	6371.9	50.23_5
L_I	91	1475.31	BCT - Ph - 53 Oxide				
				Oxide ^{b}1475.3	$6778._3$	2603.5	8.387
L_{II}	32	1558.7	SC - Ph - 23 Salt - Abs.Pk.				
	91	1559.99	BCT - Ph - 53 Oxide				
				Oxide ^{b}1560.0	$6410._3$	2531.8	7.931
L_{III}	32	1706.2 (1706.7)	SC - Ph - 23 Salt - Abs.Pk.				
	91	1708.19	BCT - Ph - 53 Oxide				
				Oxide ^{b}1708.2	$5854._1$	2419.5	7.243

65 Tb

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	71	237.92	BCT - Ph - 43 Oxide	Oxide ^{b}237.92	42031	6483.1	52.00$_5$
L_I	90	1419.38	BCT - Ph - 53 Oxide	Oxide ^{b}1419.4	7045.$_2$	2654.3	8.717
L_{II}	90	1499.16	BCT - Ph - 53 Oxide	Oxide ^{b}1499.2	6670.$_2$	2582.7	8.253
L_{III}	90	1646.33	BCT - Ph - 53 Oxide	Oxide ^{b}1646.3	6074.$_2$	2464.6	7.516

66 Dy

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	70	230.00	BCT - Ph - 43 Oxide	Oxide			
				^{b}230.00	43479	6593.8	53.79_6
L_I	32	1364.8 (1365.1)	SC - Ph - 23 Salt - Abs.Pk.				
	2	1365.51	BCT - Ph - 47 Oxide	Oxide			
				†1366.4	$7318._5$	2705.3	9.055
L_{II}	32	1441.4 (1441.3)	SC - Ph - 23 Salt - Abs.Pk.				
	2	1441.49	BCT - Ph - 47 Oxide	Oxide			
				^{b}1441.5	$6937._3$	2633.9	8.583

66 Dy

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
L_{III}	32	1587.0	SC - Ph - 23				
		(1587.5)	Salt - Abs.Pk.				
	2	1588.25	BCT - Ph - 47 Oxide				
				Oxide ^{b}1588.3	$6296._0$	2509.2	7.790

67 Ho

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	71	222.45	BCT - Ph - 44 Oxide	Oxide			
				^{b}222.45	44954	6704.8	55.62_2
L_I	89	1316.30	BCT - Ph - 53 Oxide	Oxide			
				^{b}1316.3	7351	2711.3	9.340
L_{II}	89	1387.60	BCT - Ph - 53 Oxide	Oxide			
				^{b}1387.6	7207	2684.5	8.917
L_{III}	89	1533.64	BCT - Ph - 53 Oxide	Oxide			
				^{b}1533.6	$6520._6$	2553.5	8.068

68 Er

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	67	215.22	BCT - Ph - 43 Oxide	Oxide			
				^{b}215.22	4646_4	6816.5	57.49_0
L_I	92	1267.97	BCT - Ph - 54 Oxide	Oxide			
				†1268.0	$7886._6$	2808.31	9.758
L_{II}	92	1335.81	BCT - Ph - 54 Oxide	Oxide			
				^{b}1335.8	$7486._2$	2736.1	9.263
L_{III}	92	1480.39	BCT - Ph - 54 Oxide	Oxide			
				†1480.4	$6755._0$	2599.0	8.358

NOTE: The wavelength of the L_I limit is given in reference 92 as 1276.97 XU; however the value of ν/R from the same paper and comparison with adjacent values on the modified Moseley diagram indicate that this is a misprint. The value appearing above, 1267.97, is believed to be the value actually measured.

68 Er

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
M_{IV}	50	8583	BCR - Ph - 52 Oxide	Oxide $^{d}858_3$	$1165._1$	1079.4	1.44
M_V	50	8829	BCR - Ph - 52 Oxide	Oxide $^{d}882_9$	$1132._6$	1064.2	1.40

69 Tm

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	11	208.5	RC - Ph - 23 Oxide	Oxide $^{\dagger}208.37$	4799_2	6927.6	59.38_0
L_I	91	1222.52	BCT - Ph - 53 Oxide	Oxide $^{b}1222.5$	8180	2860.1	10.121
L_{II}	91	1286.46	BCT - Ph - 53 Oxide	Oxide $^{b}1286.5$	7773	2788.0	9.618
L_{III}	91	1430.41	BCT - Ph - 53 Oxide	Oxide $^{b}1430.4$	6991	2644.1	8.659
M_V	49	8469.5	BCR - Ph - 52 Oxide	Oxide $^{d}846_9$	$1180._7$	1086.6	1.461

70 Yb

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	67	201.82	BCT - Ph - 43 Oxide	Oxide			
				^{b}201.82	4954_9	7039.1	61.30_7
L_I	1	1179.4	BCT - Ph - 42 Oxide	Oxide			
				^{b}1179.4	8479	2911.9	10.491
L_{II}	1	1240.21	BCT - Ph - 42 Oxide	Oxide			
				^{b}1240.2	8063	2839.6	9.977
L_{III}	1	1383.29	BCT - Ph - 42 Oxide	Oxide			
				^{b}1383.3	7229	2688.7	8.944

71 Lu

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	67	195.44	BCT - Ph - 43 Oxide	Oxide			
				^{b}195.44	5116_7	7153.1	63.30_8
L_I	1	1137.8	BCT - Ph - 42 Oxide	Oxide			
				^{b}1137.8	8789	2964.6	10.874
L_{II}	1	1196.04	BCT - Ph - 42 Oxide	Oxide			
				^{b}1196.0	8361	2891.6	10.345
L_{III}	1	1338.65	BCT - Ph - 42 Oxide	Oxide			
				1337.7	7475	2734.1	9.249

72 Hf

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	69	189.43	RCT - Ph - 43 Oxide	Oxide			
				^{b}189.43	5279_0	7265.7	65.31_7
L_I	68	1097.35	BCT - Ph - 42 Oxide	Oxide			
				^{b}1097.4	9112	3018.7	11.275
L_{II}	68	1152.44	BCT - Ph - 42 Oxide	Oxide			
				^{b}1152.4	8678	2945.8	10.737
L_{III}	68	1294.51	BCT - Ph - 42 Oxide	Oxide			
				^{b}1294.5	7725	2729.4	9.558

73 Ta

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	69	183.56	BCT - Ph - 43				
	calc.	[183.54]	$K_{\alpha_2}L_{II}; K_{\alpha_1}L_{III}$				
				[b]183.56	5447_8	7380.9	67.40_6
L_I	30	1059.5	SC - Ph - 49				
	29	1058.6	SC - Ph - 43				
	67	1058.82	BCT - Ph - 41				
				[c]1059.1	9442	3072.8	11.683
L_{II}	67	1111.42	BCT - Ph - 41				
				[b]1111.4	8998	2999.6	11.133
L_{III}	29	1253.4	SC - Ph - 43				
	99	1252.9	DC - Ph - 34				
	67	1252.58	BCT - Ph - 41				
				[c]1252.7	7983	2825.4	9.877

73 Ta

Disc.	Ref.	λ	Remarks	λ_γ	$\tilde{\nu}\times 10^7$	$\sqrt{\tilde{\nu}}\times 10^5$	kev
M_I	calc.	[4576]	$L_\eta L_{II}$; $L_l L_{III}$	[4576]	2185	$1478._2$	2.704
M_{II}	calc.	[5010]	$L_{\beta_4} L_I$	[501_0]	1996	$1412._8$	2.470
M_{III}	103 calc.	5647 [5638]	SC - Ph - 31 $L_{\beta_3} L_I$	[563_8]	1774	$1331._8$	2.195
M_{IV}	103 34 calc.	6773 6845 [6917]	SC - Ph - 31 SC - Ph - 52 $L_{\alpha_2} L_{III}$;$L_{\beta_1} L_{II}$	$^{\pi}686_0$	1458	$1207._4$	1.804
M_V	103 34 calc.	6997 7033 [7150]	SC - Ph - 31 SC - Ph - 31 $L_{\alpha_1} L_{III}$	$^{\pi}710_9$	1407	$1186._6$	1.740

74 W

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	8	177.995	BCT - Sc.C - 58				
	69	178.01	BCT - Ph - 43				
	62	178.22	FCT - Ph - 27				
	calc.	[177.97]	$K_{\alpha_2}L_{II}$;$K_{\alpha_1}L_{III}$				
				$^a178.00$	5618_0	7495.3	69.51
L_I	94	1023.5	TS - Ph - 30				
	29	1022.8	SC - Ph - 43				
	5	*1022.53	DC - IC - 40				
	24	1022.6	BCT - Ph - 40				
	30	1022.5	SC - Ph - 49				
				$^c1022.5_5$	$9779._5$	3127.2_2	12.100
L_{II}	94	1071.7	TS - Ph - 30				
	29	1072.8	SC - Ph - 43				
	5	*1072.15	DC - IC - 40				
	24	1072.42	BCT - Ph - 40				
				$^c1072.2_8$	$9325._9$	3053.8_4	11.539_0

74 W

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
L_{III}	94	1212.9	TS - Ph - 30				
	99	1213.4	DC - Ph - 34				
	29	1214.1	SC - Ph - 43				
	5	*1212.52	DC - IC - 40				
	24	1213.01	BCT - Ph - 40				
				^{b}1213.0	8244	2871.2	10.200
M_I	105	4365	SC - Ph - 25				
	calc.	[4398]	$L_{\eta}L_{II}$; $L_{l}L_{III}$				
				[439_8]	2740	$1508._0$	2.81_3
M_{II}	105	4800	SC - Ph - 25				
	calc.	[$4805._5$]	$L_{\beta_4}L_I$				
				[480_5]	2081	$1442._6$	2.575

74 W

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
M_{III}	105	5416	SC - Ph - 25				
	52	5427	SC - Ph - 31				
	calc.	[5424]	$L_{\beta_3}L_I$				
				[5424]	1844.6	1357.8	2.281
M_{IV}	105	6475	SC - Ph - 25				
	52	6487	SC - Ph - 31				
	calc.	[6633]	$L_{\alpha_2}L_{III}$;$L_{\beta_1}L_{II}$				
				††658_3	1519	$1232._5$	1.880
M_V	105	6708	SC - Ph - 25				
	calc.	[6864]	$L_{\alpha_1}L_{III}$				
				††681_8	1467	$1211._1$	1.815

75 Re

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	69	172.66	BCT - Ph - 43				
	calc.	[172.63]	$K_{\alpha_2}L_{II};K_{\alpha_1}L_{III}$				
				$^c172.65$	5792_1	7610.6	71.66
L_I	94	987.3	TS - Ph - 30				
	16	987.52	BCT - Ph - 37				
				$^c987.4$	10128	3182.4	12.531
L_{II}	94	1035.4	TS - Ph - 30				
	16	1034.73	BCT - Ph - 37				
				$^c1035.0$	9662	3108.4	11.955
L_{III}	94	1175.5	TS - Ph - 30				
	16	1174.63	BCT - Ph - 37				
				$^c1174.9$	8511	2917.4	10.531

75 Re

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
M_I	calc.	[4227]	$L_\eta L_{II}$; $L_\eta L_{III}$	$[422_7]$	2366	$1538._1$	2.92_7
M_{II}	calc.	[4609.6]	$L_{\beta_4} L_I$	$[461_0]$	2169	$1472._9$	2.684
M_{III}	calc.	$[5219._4]$	$L_{\beta_3} L_I$	$\#522_3$	1915	$1383._7$	2.369
M_{IV}	calc.	[6364]	$L_{\alpha_2} L_{III}$; $L_{\beta_1} L_{II}$	$\#631_7$	1583	$1258._2$	1.959
M_V	Calc.	$[6587._4]$	$L_{\alpha_1} L_{III}$	$\#654_7$	1527	$1235._9$	1.890

76 Os

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	69	167.46	BCT - Ph - 43				
	62	167.55	FCT - Ph - 27				
	calc.	[167.49]	$K_{\alpha_2}L_{II}$;$K_{\alpha_1}L_{III}$				
				^{c}167.47	5971_2	7727.3	73.88
L_I	94	955.8	TS - Ph - 30				
	27	953.75	BCT - Ph - 46				
				^{b}953.8	10484	3238.0	12.972
L_{II}	94	999.8	TS - Ph - 30				
	27	999.02	BCT - Ph - 46				
				^{c}999.3	10007	3163.4	12.382
L_{III}	94	1139.0	TS - Ph - 30				
	27	1138.13	BCT - Ph - 46				
				^{c}1138.4	8784	2963.8	10.869

76 Os

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
M_I	84	4037	SC - Ph - 27 Oxide				
	calc.	[4063]	$L_\eta L_{II}; L_\iota L_{III}$				
				$[406_3]$	2461	$1568._8$	3.04_5
M_{II}	84	4412	SC - Ph - 27 Oxide				
	calc.	$[4424._5]$	$L_{\beta_4} L_I$				
				$[442_4]$	2260	$1503._4$	2.79_7
M_{III}	84	5027	SC - Ph - 27 Oxide				
	calc.	[5028]	$L_{\beta_3} L_I$				
				$\dagger\dagger 503_3$	1987	$1409._6$	2.458
M_{IV}	84	5975	SC - Ph - 27 Oxide				
	calc.	[6105]	$L_{\alpha_2} L_{III}; L_{\beta_1} L_{II}$				
				$\dagger\dagger 606_0$	1650	$1284._6$	2.042

76 Os

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
M_V	84	6194	SC - Ph - 27				
	calc.	[6324]	Oxide $L_{\alpha_1}L_{II}$				
				$^{\dagger\dagger}628_6$	1591	$1261._3$	1.968

77 Ir

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	69	162.53	BCT - Ph - 43				
	62	162.09	FCT - Ph - 27				
	calc.	162.57	$K_{\alpha_2}L_{II};K_{\alpha_1}L_{III}$				
				†162.58	61504	7840.9	76.10
L_I	94	922.3	TS - Ph - 30				
	25	921.14	BCT - Ph - 45				
				^{c}921.7	10849	3293.9	13.424
L_{II}	94	965.4	TS - Ph - 30				
	25	965.00	BCT - Ph - 45				
				^{c}965.1	10362	3218.9	12.820
L_{III}	94	1103.8	TS - Ph - 30				
	25	1103.42	BCT - Ph - 45				
				^{c}1103.5	9062	3010.3	11.212

77 Ir

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu}\times 10^7$	$\sqrt{\tilde{\nu}}\times 10^5$	kev
M_I	calc.	[3907]	$L_{\eta}L_{II};L_{\ell}L_{III}$				
				[390_7]	2560	$1599._9$	3.167
M_{II}	84	4270	SC - Ph - 27				
	calc.	[4248]	Chloride $L_{\beta_4}L_I$				
				$^{\dagger\dagger}425_1$	2352	$1533._7$	2.91_1
M_{III}	84	4851	SC - Ph - 27				
	calc.	[$4840._6$]	Chloride $L_{\beta_3}L_I$				
				$^{b}4851$	$2061._4$	1435.8	2.551
M_{IV}	84	5754	SC - Ph - 27				
	calc.	[$5858._5$]	Chloride $L_{\alpha_2}L_{III};L_{\beta_1}L_{II}$				
				$^{\dagger\dagger}581_6$	1719	$1311._2$	2.217

77 Ir

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
M_V	84	5961	SC - Ph - 27				
	calc.	[6074]	Chloride				
			$L_{\alpha_1}L_{III}$	††603_8	1656	$1286._9$	2.049

78 Pt

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	71 62 calc.	157.85 157.70 [157.82]	BCT - Ph - 44 FCT - Ph - 27 $K_{\alpha_2} L_{II} ; K_{\alpha_1} L_{III}$				
				[b]157.85	6335_1	7959.4	78.38
L_I	94 24 5	891.4 891.4 *890.88	TS - Ph - 30 BCT - Ph - 40 DC - IC - 40				
				[c]891.2	11221	3349.7	13.884
L_{II}	94 24 5	932.1 932.33 *932.13	TS - Ph - 30 PCT - Ph - 40 DC - IC - 40				
				[c]932.2	10727	3295.3	13.273
L_{III}	94 7 24	1071.0 *1070.0 1070.23	TS - Ph - 30 DC - Ph - 39 BCT - Ph - 40				
				[c]1070.1	9345	3056.9	11.562

78 Pt

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
M_I	45	3742	SC - Ph - 29				
	84	3738	SC - Ph - 27				
			Chloride				
	calc.	[3754.$_5$]	$L_\eta L_{II}; L_\iota L_{III}$				
				[375$_4$]	2663	1599.$_9$	3.296
M_{II}	45	4085	SC - Ph - 29				
	calc.	[4085]	$L_{\beta_4} L_I$				
				[b]408$_5$	2448	1564.$_5$	3.02$_9$
M_{III}	52	4677	SC - Ph - 31				
	45	4677	SC - Ph - 29				
	84	4674	SC - Ph - 27				
			Chloride				
	calc.	[4665]	$L_{\beta_3} L_I$				
				[c]4676	2138.$_6$	1462.4	2.646

78 Pt

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
M_{IV}	52	5545	SC - Ph - 31				
	45	5506	SC - Ph - 29				
	84	5541	SC - Ph - 27				
			Chloride				
	calc.	[5622]	$L\alpha_2 L_{III}; L\beta_1 L_{II}$				
				$^{\uparrow\uparrow}558_4$	1791	$1338._2$	2.216
M_V	52	5746	SC - Ph - 31				
	45	5711	SC - Ph - 29				
	84	5736	SC - Ph - 27				
			Chloride				
	calc.	[5837]	$L\alpha_1 L_{III}$				
				$^{\uparrow\uparrow}580_0$	1724	$1313._0$	2.133

79 Au

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	6	153.275	BCT - Sc.C - 59				
	71	153.13	BCT - Ph - 44				
	62	153.20	FCT - Ph - 27				
	calc.	[153.266]	$K_{\alpha_2}L_{II}; K_{\alpha_1}L_{III}$				
				$^{a}153.27_5$	65242	8077.3	80.72_4
L_I	94	862.2	TS - Ph - 30				
	66	861.97	BCT - Ph - 56				
	18	861.63	BCT - Ph - 42				
	83	861.3	DC - IC - 34				
				$^{a}861.9_7$	$11601._3$	3406.1	14.354
L_{II}	94	900.9	TS - Ph - 30				
	63	900.70	BCT - Ph - 55				
	18	900.74	BCT - Ph - 42				
	83	900.3	DC - IC - 34				
				$^{c}900.7_5$	$11101._8$	3331.9	13.736

79 Au

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
L_{III}	94 99 63 18 83	1038.2 1037.8 1037.86 1037.84 1037.7	TS - Ph - 30 DC - IC - 34 BCT - Ph - 55 PCT - Ph - 42 DC - IC - 34				
				$^c1037.8_5$	$9635._3$	3104.1	11.922
M_I	45 calc.	3603 [3609]	SC - Ph - 29 L_η L_{II};L_l L_{III}				
				[360_9]	2771	$1664._5$	3.42_8
M_{II}	calc.	[3928]	$L_{\beta_4}L_I$				
				[392_8]	2546	$1595._5$	3.15_0

79 Au

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
M_{III}	52	4508	SC - Ph - 31				
	45	4501	SC - Ph - 29				
	65	4509	BCR - Ph - 57				
	calc.	$[4509._1]$	$L_{\beta_3}L_I$				
				$^a4509$	$2217._8$	1489.2	2.744
M_{IV}	52	5330	SC - Ph - 31				
	45	5315	SC - Ph - 29				
	65	5363	BCR - Ph - 57				
	calc.	[5394]	$L_{\alpha_2}L_{III};L_{\beta_1}L_{II}$				
				$^a5363$	$1864._6$	1365.5	2.307
M_V	52	5529	SC - Ph - 31				
	45	5506	SC - Ph - 29				
	65	5572	BCR - Ph - 57				
	calc.	[5603]	$L_{\alpha_1}L_{III}$				
				$^a5572$	$1794._7$	1339.7	2.22_1

80 Hg

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	62 calc.	148.93 [148.87]	FCT - Ph - 27 liquid $K\alpha_2 L_{II}; K\alpha_1 L_{III}$	[148.87]	6717_3	$8195._9$	83.11
L_I	14	833.6	BCT - Ph - 37 liquid	$^b833.6$	11996	3463.6	14.842_8
L_{II}	14	870.4	BCT - Ph - 37 liquid	$^b870.4$	11489	3389.5	14.215
L_{III}	14 39	1006.95 1006.7	BCT - Ph - 37 liquid SC - Ph - 31 gas	$^b1007.0$	9930	3151.3	12.287
M_I	calc.	[3470.6]	$L\eta L_{II}; L\iota L_{III}$	$[347_1]$	2882	$1697._4$	3.56_5

80 Hg

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
M_{II}	calc.	[3775.2]	$L_{\beta_4}L_I$				
				$[377_5]$	2649	$1627._5$	3.27_8
M_{III}	52	4340	SC - Ph - 31 Sulfide				
	calc.	[4349]	$L_{\beta_4}L_I$				
				‡4346	$2300._9$	1516.9	2.847
M_{IV}	52	5138	SC - Ph - 31 Chloride				
	calc.	[5180.4]	$L_{\alpha_2}L_{III}$				
				‡5146	$1943._1$	1393.9	2.404
M_V	52	5332	SC - Ph - 31 Chloride				
	calc.	[5385]	$L_{\alpha_1}L_{III}$				
				‡5353	$1868._2$	1366.8	2.311

81 Tl

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	62 calc.	144.41 [144.65]	FCT - Ph - 27 $K_{\alpha_2}L_{II}$;$K_{\alpha_1}L_{III}$	[144.65]	6913_2	8314.6	85.54
L_I	94 17	807.2 806.38	TS - Ph - 30 BCT - Ph - 42	^{b}806.4	12401	3521.5	15.343_5
L_{II}	94 17	841.9 841.67	TS - Ph - 30 BCT - Ph - 42	^{b}841.7	11881	3446.8	14.700_0
L_{III}	94 17	977.8 977.33	TS - Ph - 30 BCT - Ph - 42	^{b}977.3	10232	3198.8	12.660

81 Tl

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
M_I	calc.	[3338.7]	$L_\eta L_{II}; L_\ell L_{III}$	$[333_9]$	2995	$1697._4$	3.70_6
M_{II}	calc.	[3626]	$L_{\beta_4} L_I$	$[362_6]$	2758	$1660._1$	3.41_2
M_{III}	52 calc.	4185 [4191]	SC - Ph - 31 $L_{\beta_3} L_I$	#4189	$2387._3$	1545.1	2.954
M_{IV}	52 calc.	4936 [4976]	SC - Ph - 31 $L_{\alpha_2} L_{III}; L_{\beta_1} L_{II}$	#4942	$2023._5$	1422.5	2.504
M_V	52 calc.	5136 [5174]	SC - Ph - 31 $L_{\alpha_1} L_{III}$	#5142	$1944._6$	1394.5	2.406

82 Pb

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K		140.588	DC - IC - 60				
	62	140.49	FCT - Ph - 27				
	calc.	$[140.58_0]$	$K\alpha_2 L_{II}; K\alpha_1 L_{III}$				
				$^a 140.58_8$	71130	8433.9	88.00_9
L_I	94	781.2	TS - Ph - 30				
	15	779.94	BCT - Ph - 42				
	38	780.34	BCT - Ph - 58				
				$^a 780.3_4$	12815	3579.8	15.856
L_{II}	94	814.3	TS - Ph - 30				
	15	813.44	BCT - Ph - 42				
	38	813.69	BCT - Ph - 58				
				$^a 813.6_9$	12290	3505.7	15.206
L_{III}	94	949.2	TS - Ph - 30				
	15	948.37	BCT - Ph - 42				
	38	948.76	BCT - Ph - 58				
				$^a 948.7_6$	$10540._1$	3246.6	13.041

82 Pb

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
M_I	72 calc.	3219 [3205]	SC - Ph - 39 $L_\eta L_{II}; L_l L_{III}$	#3210	3115	1765.$_1$	3.854
M_{II}	72 calc.	3469 [3485]	SC - Ph - 39 $L_{\beta_4} L_I$	[3485]	2869	1693.$_8$	3.55$_0$
M_{III}	52 calc.	4033 [4041]	SC - Ph - 31 $L_{\beta_3} L_I$	#4039	2476	1573.4	3.063
M_{IV}	52 calc.	4747 [4774]	SC - Ph - 31 $L_{\alpha_2} L_{III}; L_{\beta_1} L_{II}$	^{b}4747	2106.$_6$	1451.4	2.606
M_V	52 calc.	4945 [4970.$_5$]	SC - Ph - 31 $L_{\alpha_1} L_{III}$	^{b}4945	2022.$_2$	1422.0	2.502

83 Bi

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	62	136.78	SC - Ph - 27				
	calc.	[136.66]	$K\alpha_2\ L_{II}; K\alpha_1\ L_{III}$				
				[136.66]	7317_4	$8554._2$	90.54
L_I	94	755.9	TS - Ph - 30				
	20	755.26	BCT - Ph - 12				
				$^c755.4_7$	13237	3638.3	16.378
L_{II}	94	787.8	TS - Ph - 30				
	20	787.12	BCT - Ph - 12				
				$^b787.1_2$	12704	3564.3	15.719
L_{III}	94	922.1	TS - Ph - 3[illegible]				
	20	921.50	BCT - Ph - [illegible]				
				$^b921.5_0$	$10851._9$	3294.2	13.427
M_I	81	3100	SC - Ph - 3[illegible]				
	calc.	[$3087._6$]	$L\eta\ L_{II}; L\ell\ L_{III}$				
				[3088]	3239	1799.7	4.007

83 Bi

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
M_{II}	81	3342	SC - Ph - 34				
	calc.	[3352.4]	$L_{\beta_4} L_I$				
				[3352]	2983	1727.1	3.691
M_{III}	52	3893	SC - Ph - 31				
	81	3889	SC - Ph - 34				
	calc.	[3901]	$L_{\beta_3} L_I$				
				π3896	2566	1602.0	3.176
M_{IV}	52	4568	SC - Ph - 31				
	81	4574	SC - Ph - 34				
	calc.	[4590]	$L_{\alpha_2} L_{III}$;$L_{\beta_1} L_{II}$				
				$\pi 456_3$	2192	$1480._4$	2.71_2
M_V	52	4762	SC - Ph - 31				
	81	4753	SC - Ph - 34				
	calc.	[4781]	$L_{\alpha_1} L_{III}$				
				$\pi 475_6$	2102	$1450._4$	2.602

88 Ra

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
L_I	41	643.20	BCT - Ph - 37 Chloride				
				$^d643.2$	15547	3943.0	19.23_7
L_{II}	41	669.34	BCT - Ph - 37 Chlorure				
				$^d669.3$	14940	3865.2	18.48_6
L_{III}	41	801.09	BCT - Ph - 37 Chlorure				
				$^d801.1$	12483	3533.1	15.44_5

90 Th

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	62	112.70	SC - Ph - 27				
				$^{d}112.7$	887_{31}	942_0	109.8
L_I	94	603.9	TS - Ph - 30 Oxide				
	22	604.55	BCT - Ph - 40 Oxide	Oxide			
				$^{d}604.6$	1654_8	$4066._9$	20.46_5
L_{II}	94	629.3	TS - Ph - 30 Oxide				
	22	628.56	BCT - Ph - 40 Oxide	Oxide			
				$^{d}628.6$	1590_8	$3988._5$	19.68_3

90 Th

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
L_{III}	94	760.0	TS - Ph - 30 Oxide				
	22	759.09	BCT - Ph - 40 Oxide	Oxide			
				$^d759.1$	13173	$3629._5$	16.30_0
M_{III}	52	3062	SC - Ph - 31				
				$^d306_2$	326_6	$1807._1$	4.04_1
M_{IV}	52	3550	SC - Ph - 31				
				$^d355_0$	281_7	$1678._4$	3.48_5
M_V	52	3721	SC - Ph - 31				
				$^d372_1$	268_7	$1639._3$	3.32_5

92 U

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
K	62	106.58	SC - Ph - 27 Acetate				
				$^{d}106.6$	938_{09}	968_6	$116._1$
L_I	94	568.0	TS - Ph - 30 Oxide				
	24	568.28	RCT - Ph - 40				
				$^{d}568.3$	1759_6	$4194._7$	21.77_2
L_{II}	94	591.3	**TS** - Ph - 30 Oxide				
	24	590.71	RCT - Ph - 40				
				$^{d}590.7$	1692_9	$4114._5$	20.94_6
L_{III}	94	720.8	TS - Ph - 30 Oxide				
	24	720.76	RCT - Ph - 40				
				$^{d}720.8$	13873	3724.6	17.16_6

92 U

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
M_{III}	52	2878	SC - Ph - 31	$^{d}287_8$	3475	$1864._0$	4.299
M_{IV}	52	3326	SC - Ph - 31	$^{d}332_6$	3007	$1733._9$	3.72_0
M_V	52	3490	SC - Ph - 31	$^{d}349_0$	2865	$1692._7$	3.54_5

94 Pu

Disc.	Ref.	λ	Remarks	λ_r	$\tilde{\nu} \times 10^7$	$\sqrt{\tilde{\nu}} \times 10^5$	kev
L_I	26	535.4	BCT - Ph - 54 Oxide	$^d535.4$	1867_8	$4321._8$	23.11
L_{II}	26	555.95	BCT - Ph - 54 Oxide	$^d555.9_5$	17987	4241.3	22.256
L_{III}	26	685.25	BCT - Ph - 54 Oxide	$^d685.2_5$	14593	3820.1	18.056

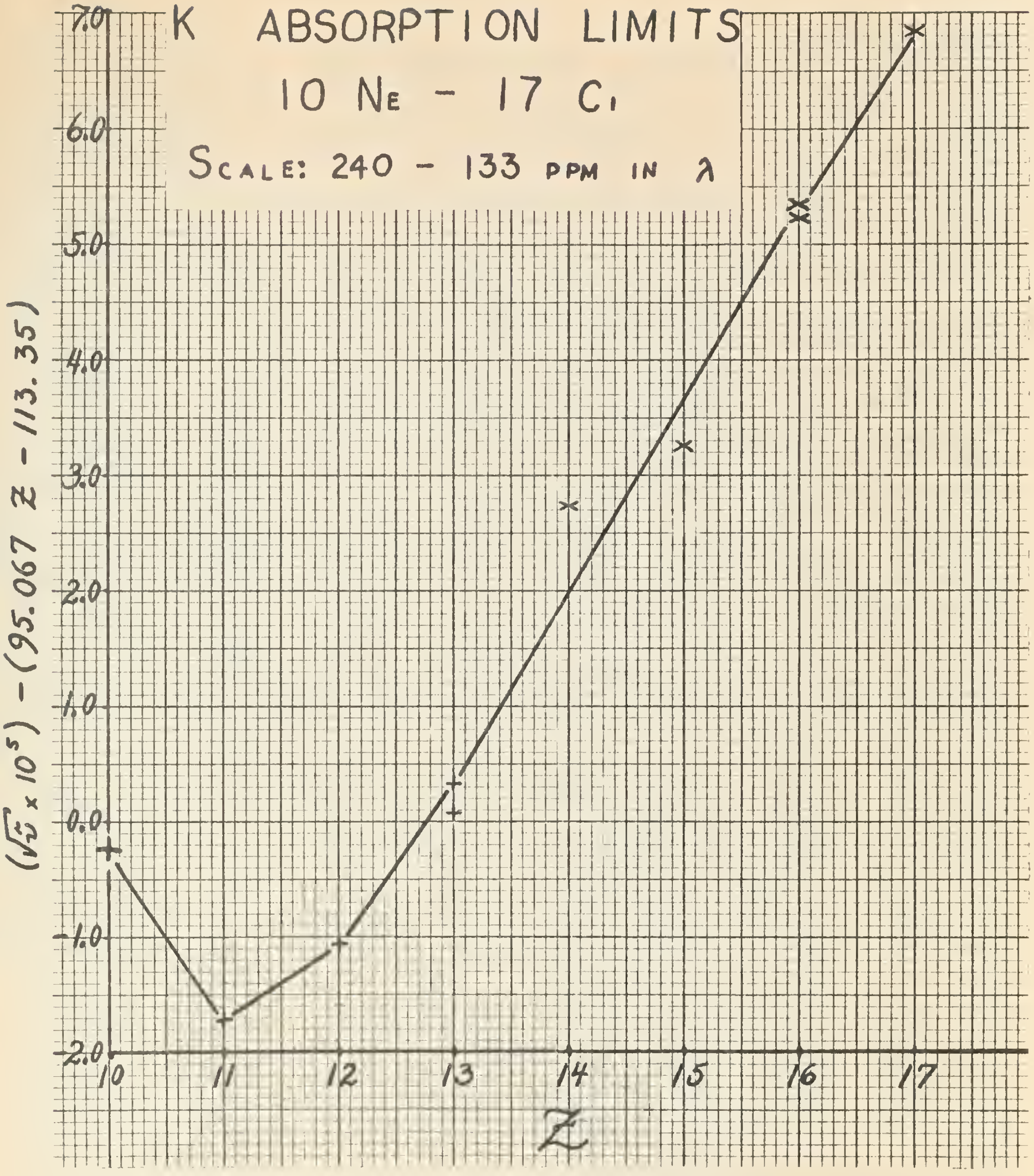
APPENDIX A

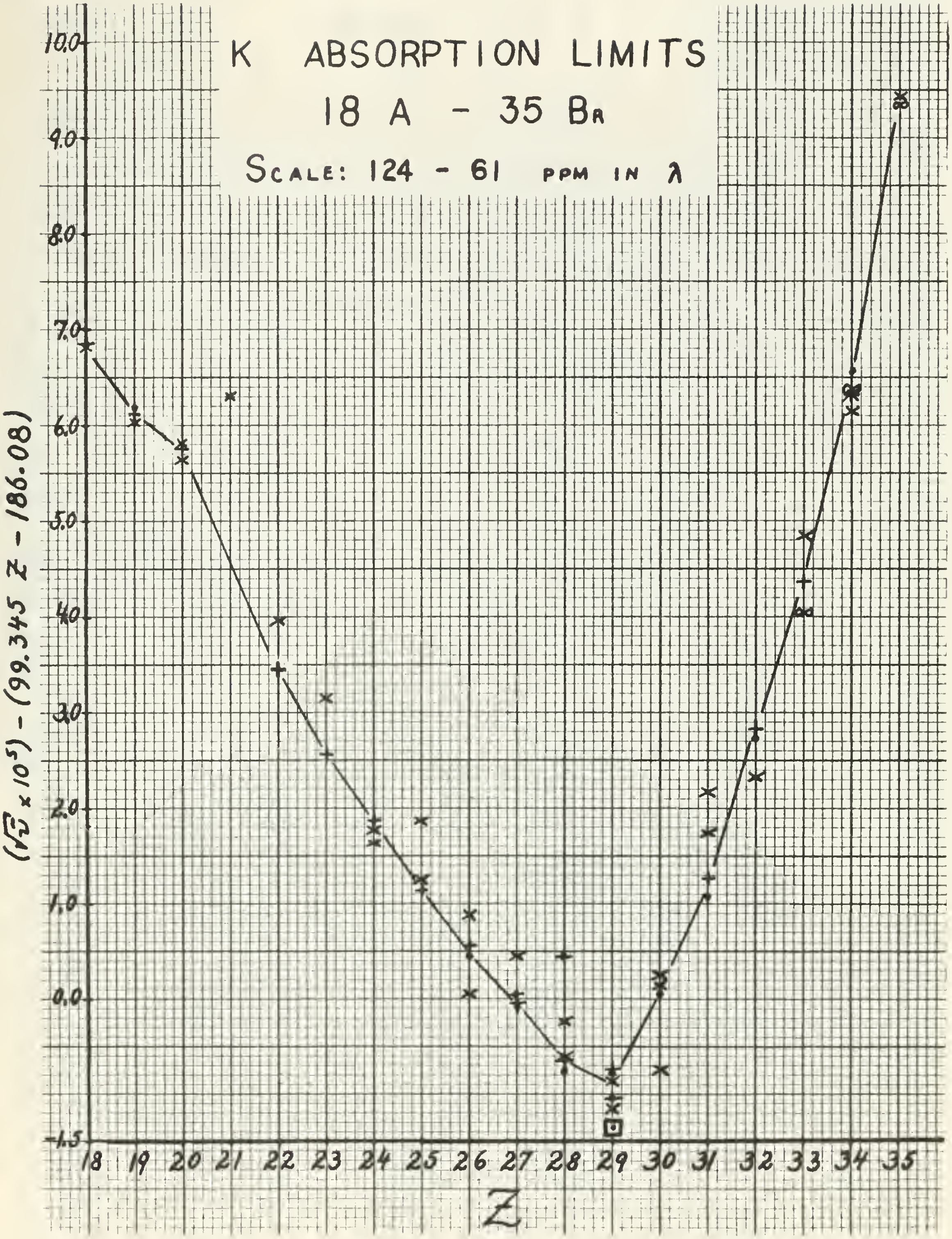
Modified Moseley Diagrams

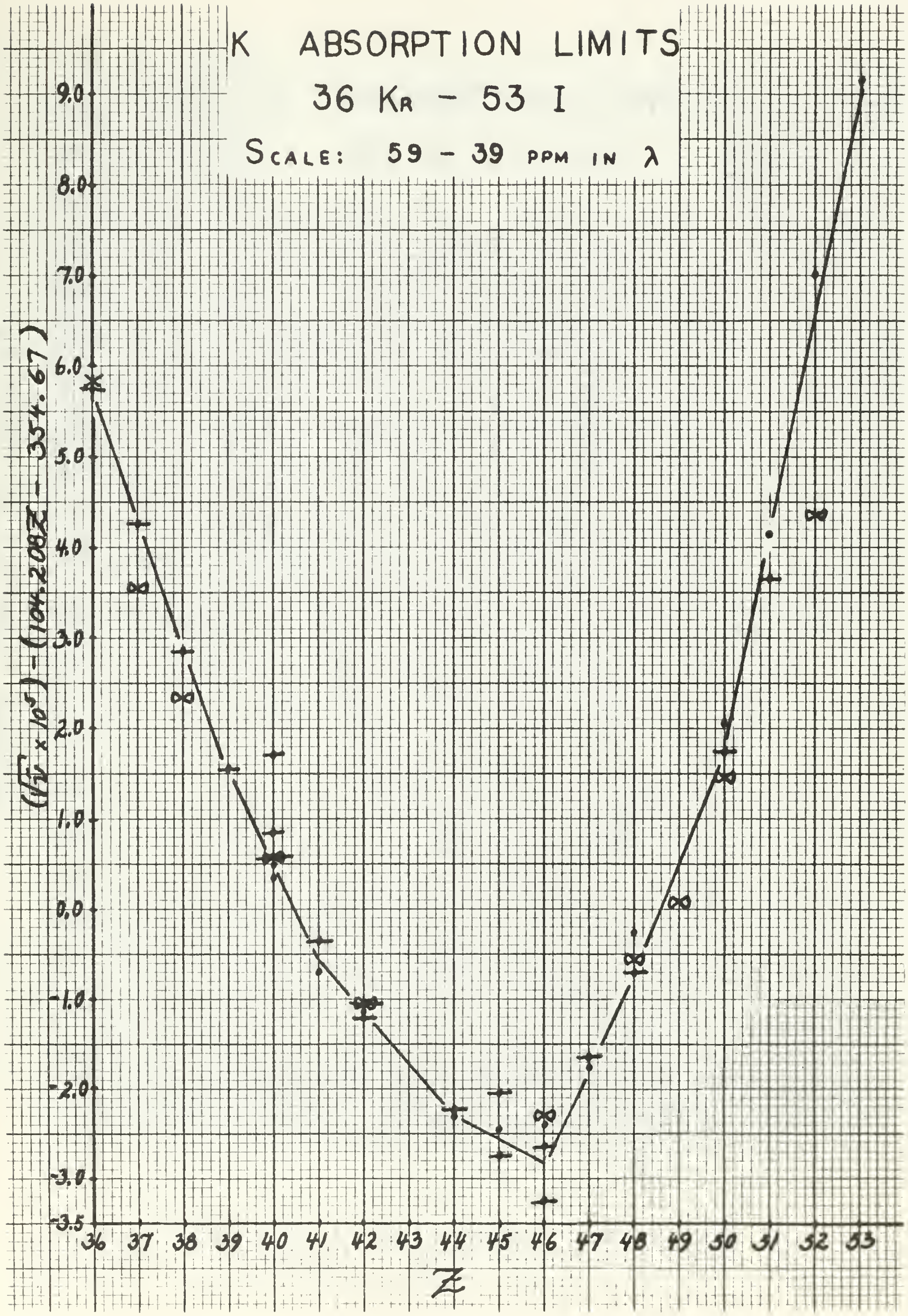
Key to symbols used:

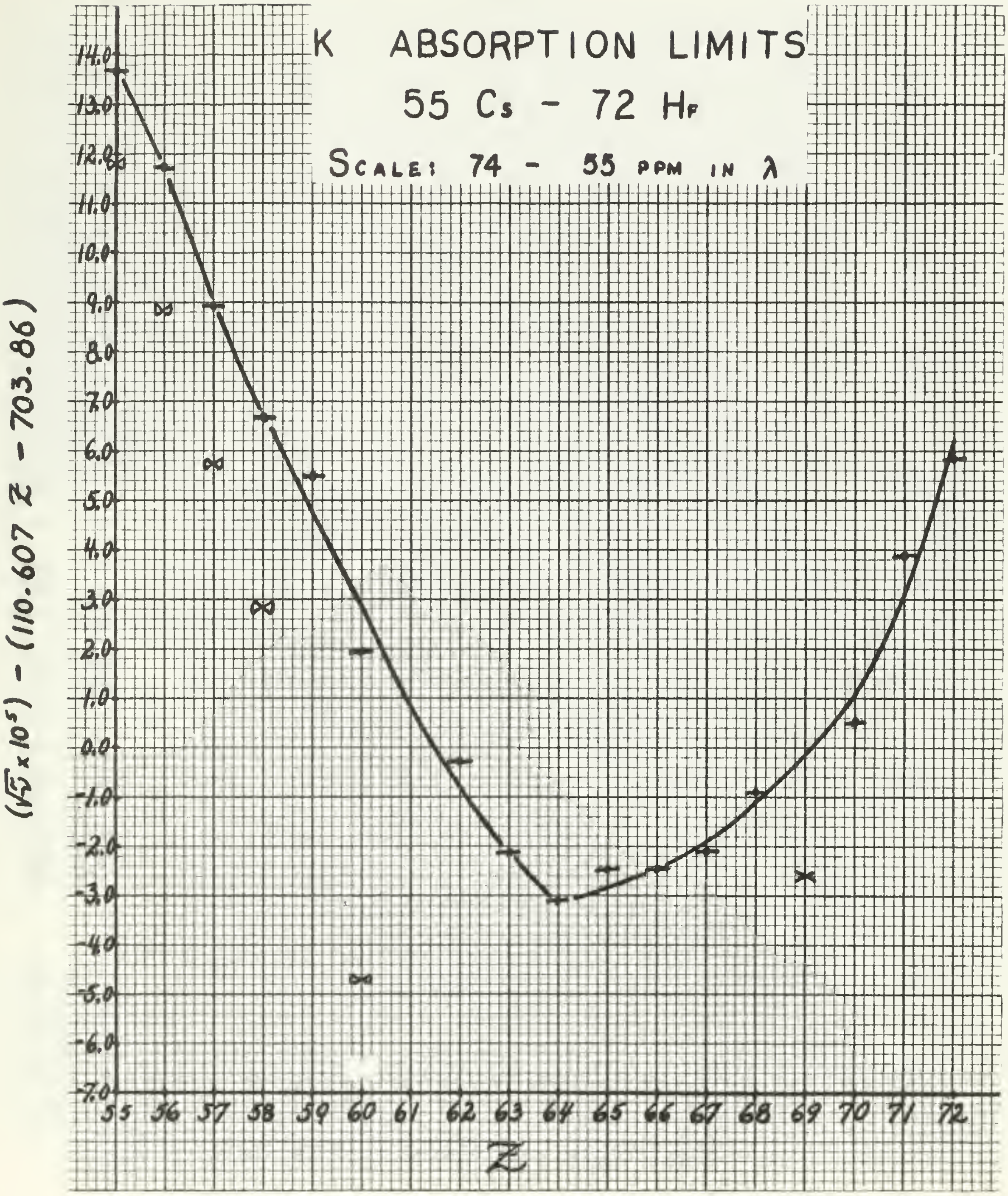
×	Single crystal spectrometer
+	Bent crystal spectrometer, reflection
-•-	Bent crystal spectrometer, transmission
●	Double crystal spectrometer
∞	Tube spectrograph
⊙	Calculated values
◬	Flat crystal spectrograph (62)

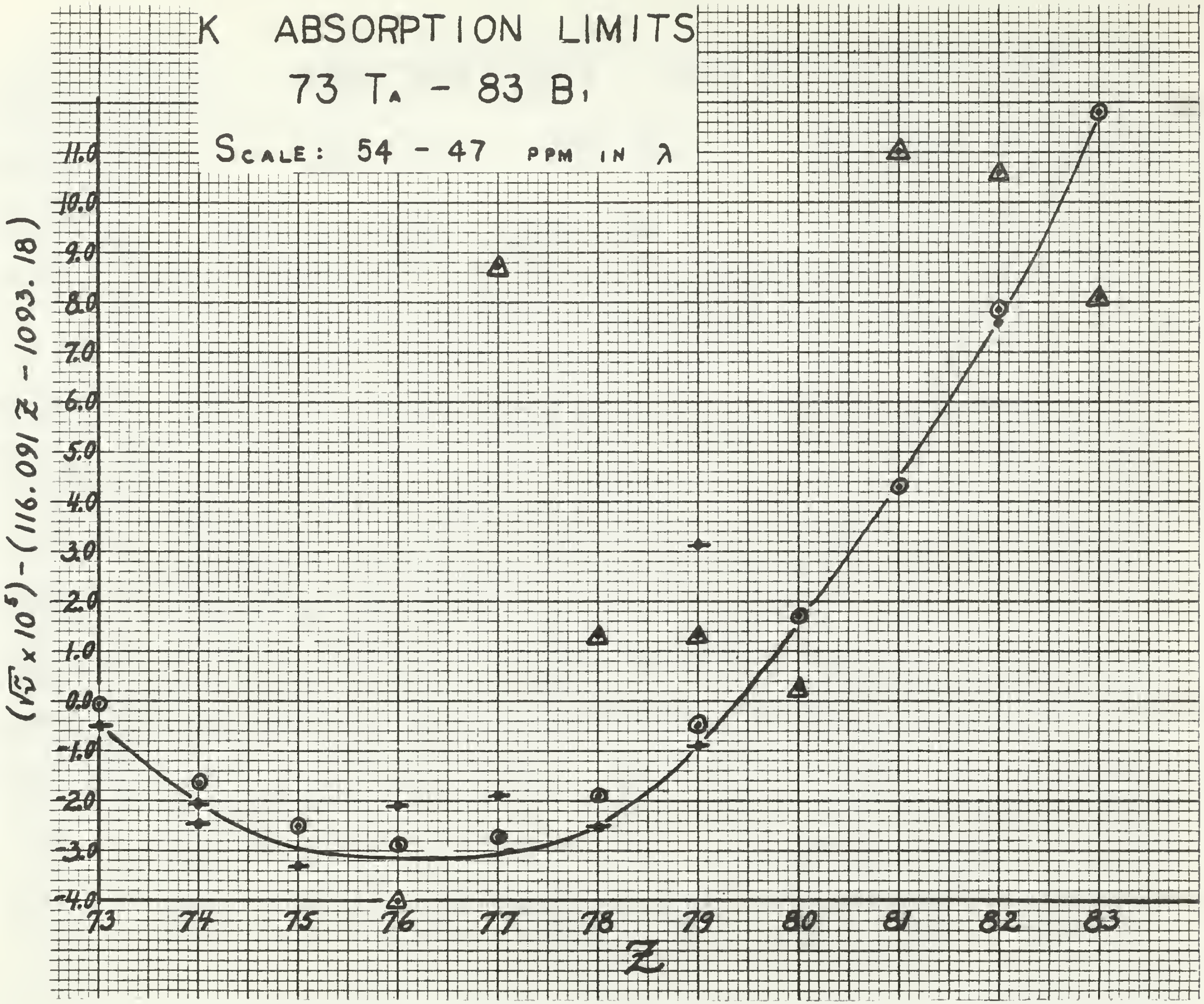
The scale given on each of the following diagrams is the variation of wavelength in parts per million corresponding to a distance of one of the smallest divisions on the verticle scale. This variation changes non-linearly with wavelength and is given for the elements of lowest and highest atomic number respectively on each diagram.

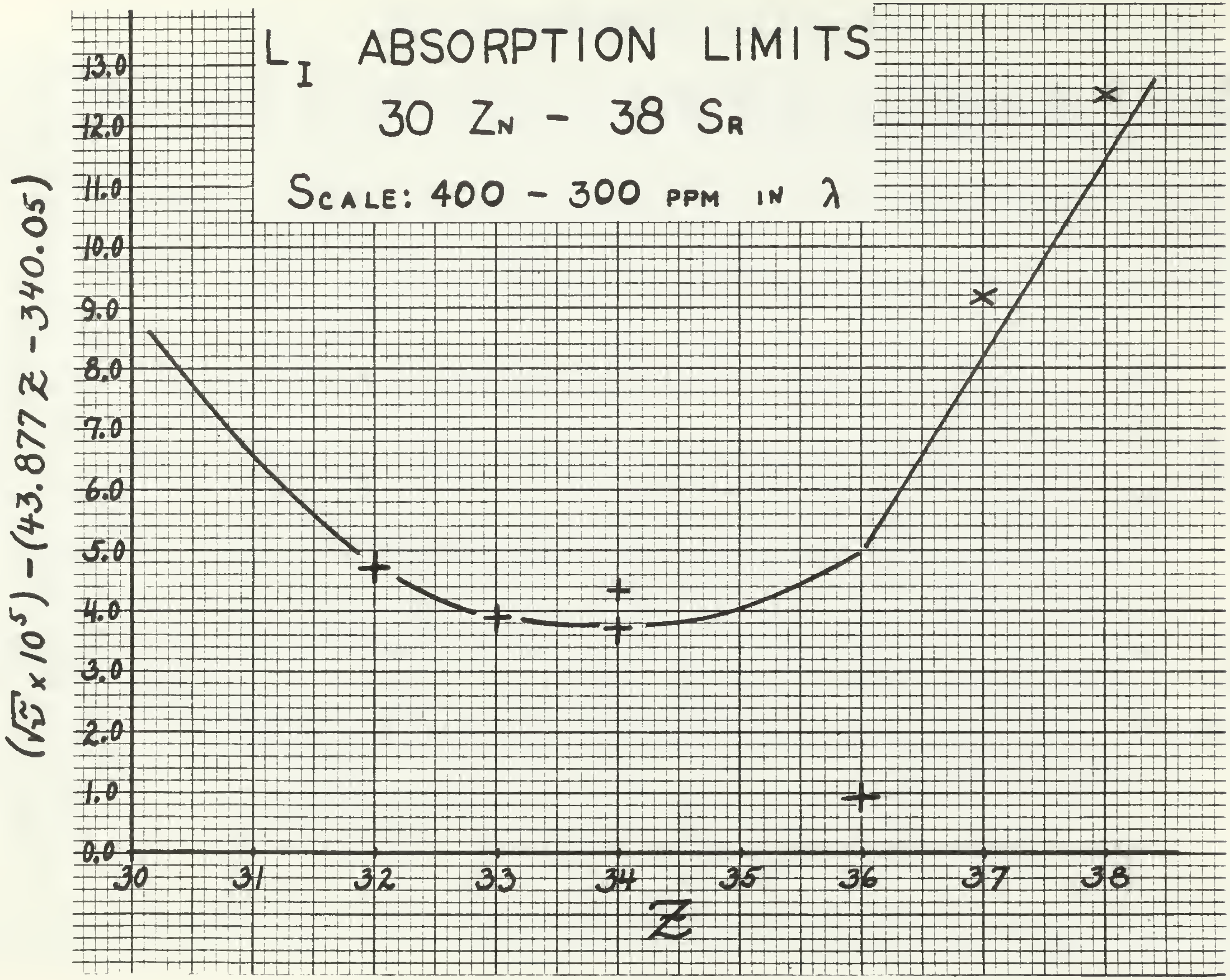

K ABSORPTION LIMITS
10 Ne - 17 Cl
Scale: 240 - 133 ppm in λ
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
10
11
12
13
14
15
16
17
Z
$(\sqrt{\nu/R} \times 10^5) - (95.067\ Z - 113.35)$

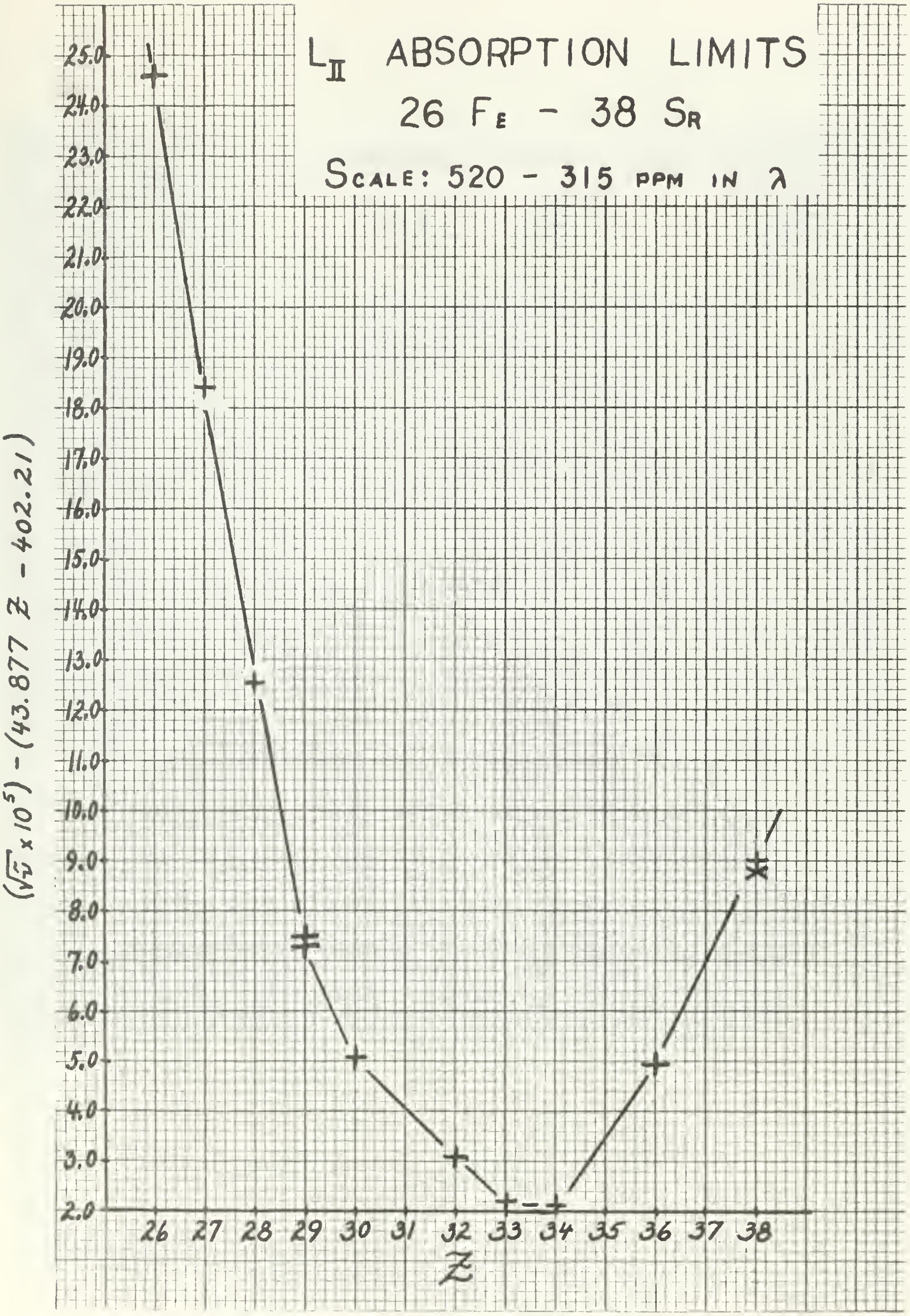

K ABSORPTION LIMITS
18 A - 35 Br
Scale: 124 - 61 ppm in λ
$(\sqrt{\nu} \times 10^5) - (99.345\ Z - 186.08)$
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.5
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
Z

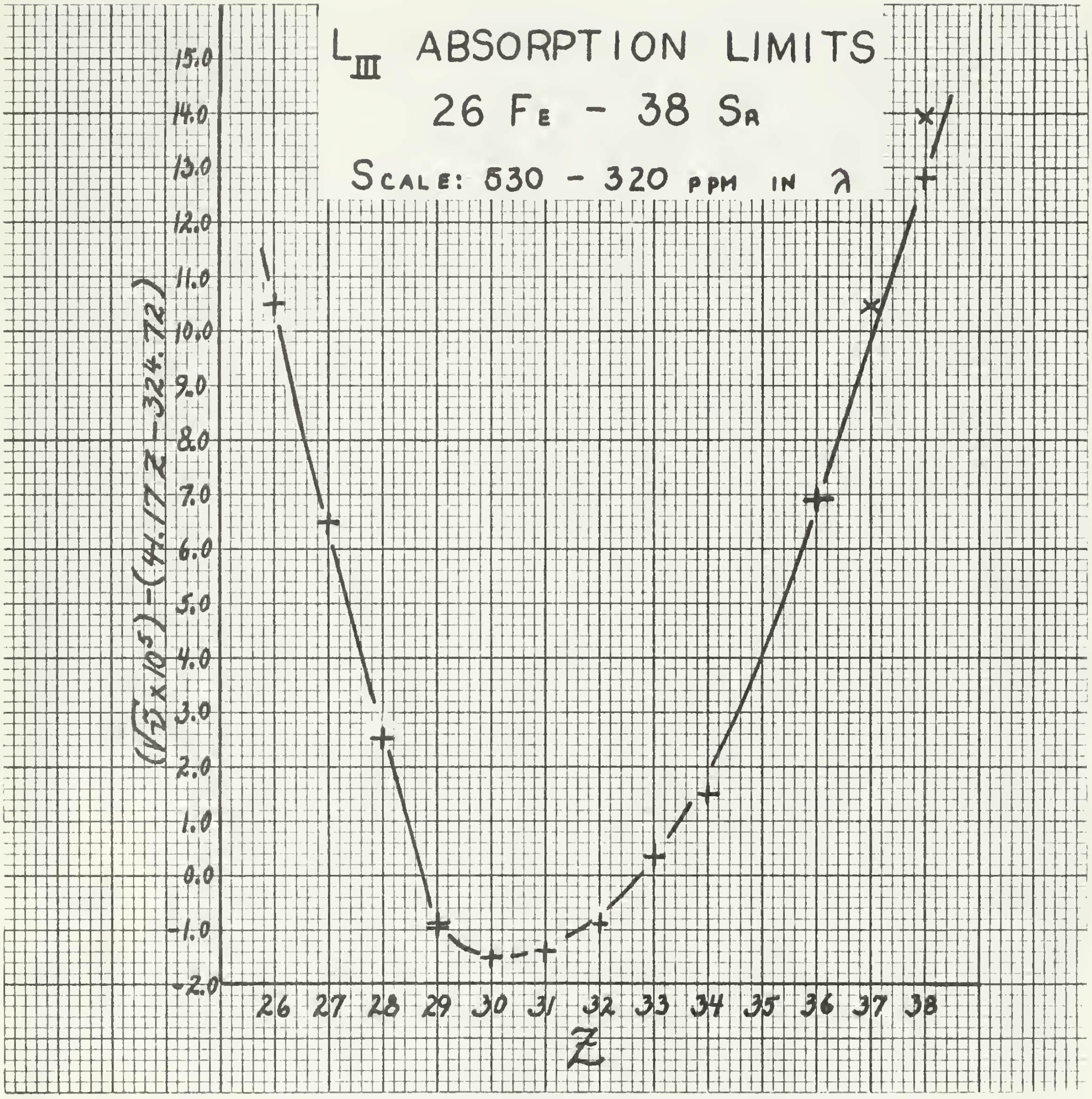

K ABSORPTION LIMITS
36 Kr - 53 I
Scale: 59 - 39 ppm in λ
$(\frac{1}{\sqrt{\nu}} \times 10^5) - (104.208Z - 354.67)$
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-3.5
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
Z

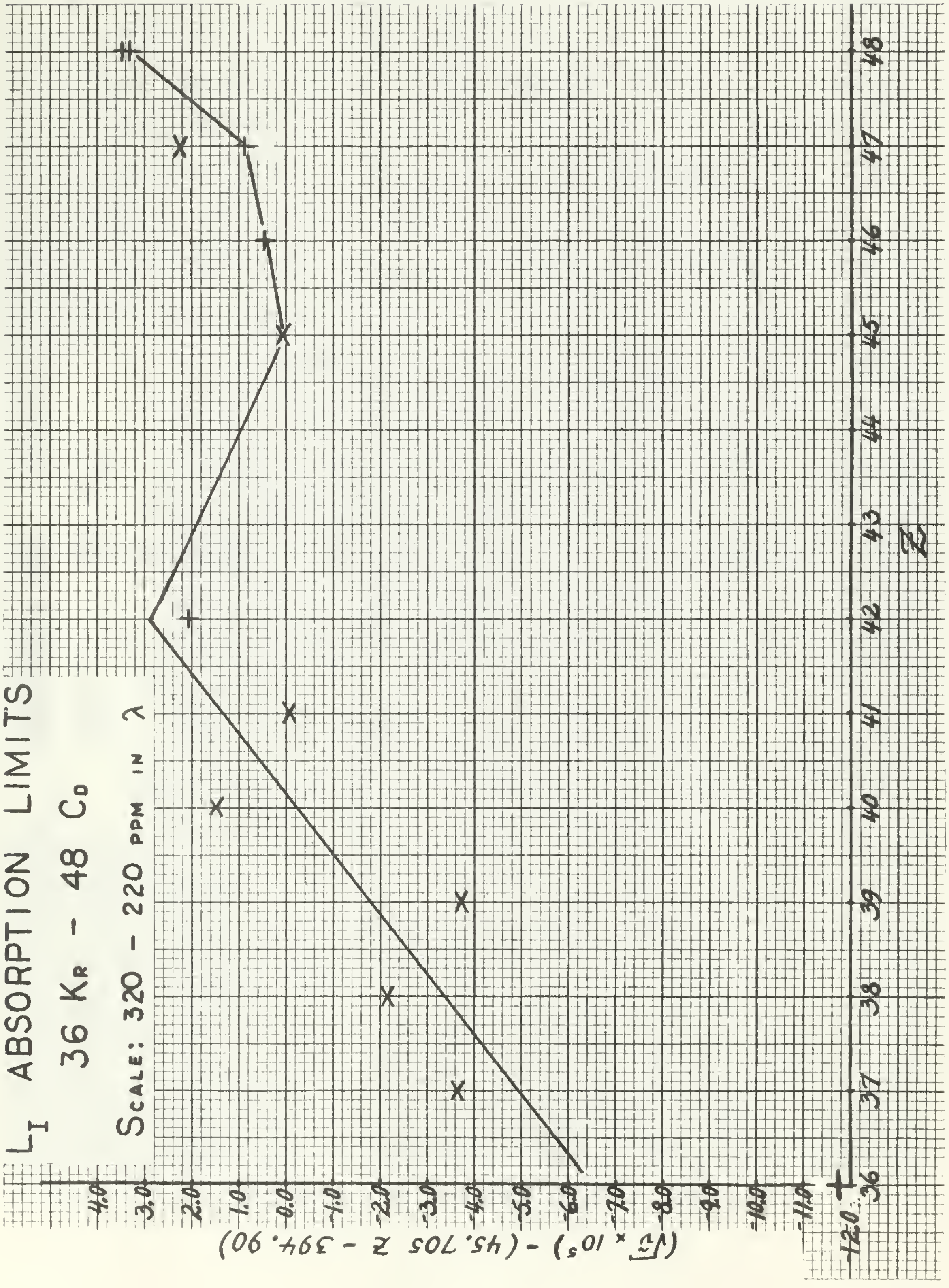

K ABSORPTION LIMITS
55 Cs - 72 Hf
Scale: 74 - 55 ppm in λ
$(\sqrt{\nu}\times 10^5) - (110.607\ Z - 703.86)$
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
-7.0
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
Z

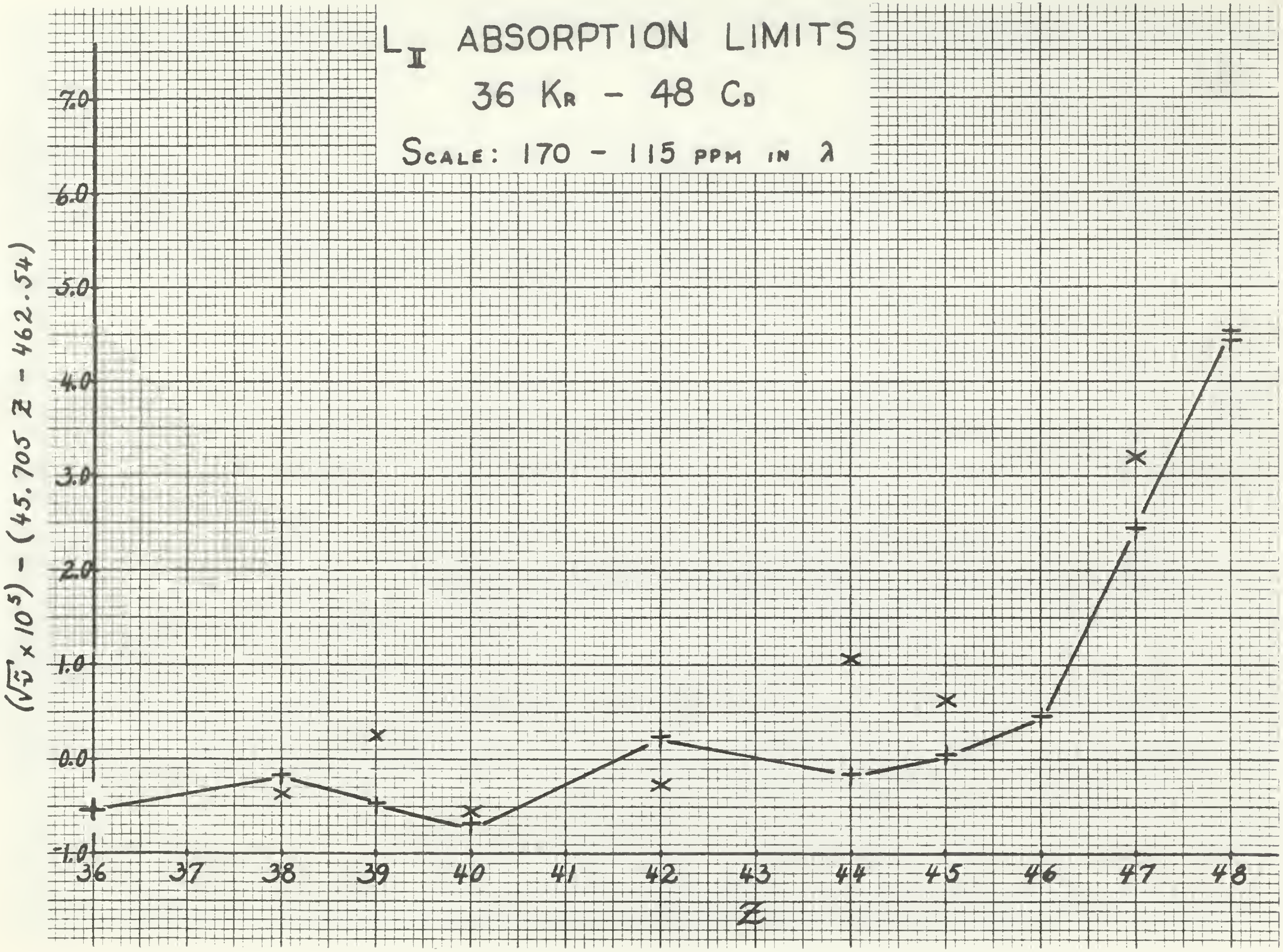

K ABSORPTION LIMITS
73 TA - 83 BI
SCALE: 54 - 47 PPM IN λ
(√(ν/R) x 10^5) - (116.091 Z - 1093.18)
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.00
-1.0
-2.0
-3.0
-4.0
73
74
75
76
77
78
79
80
81
82
83
Z

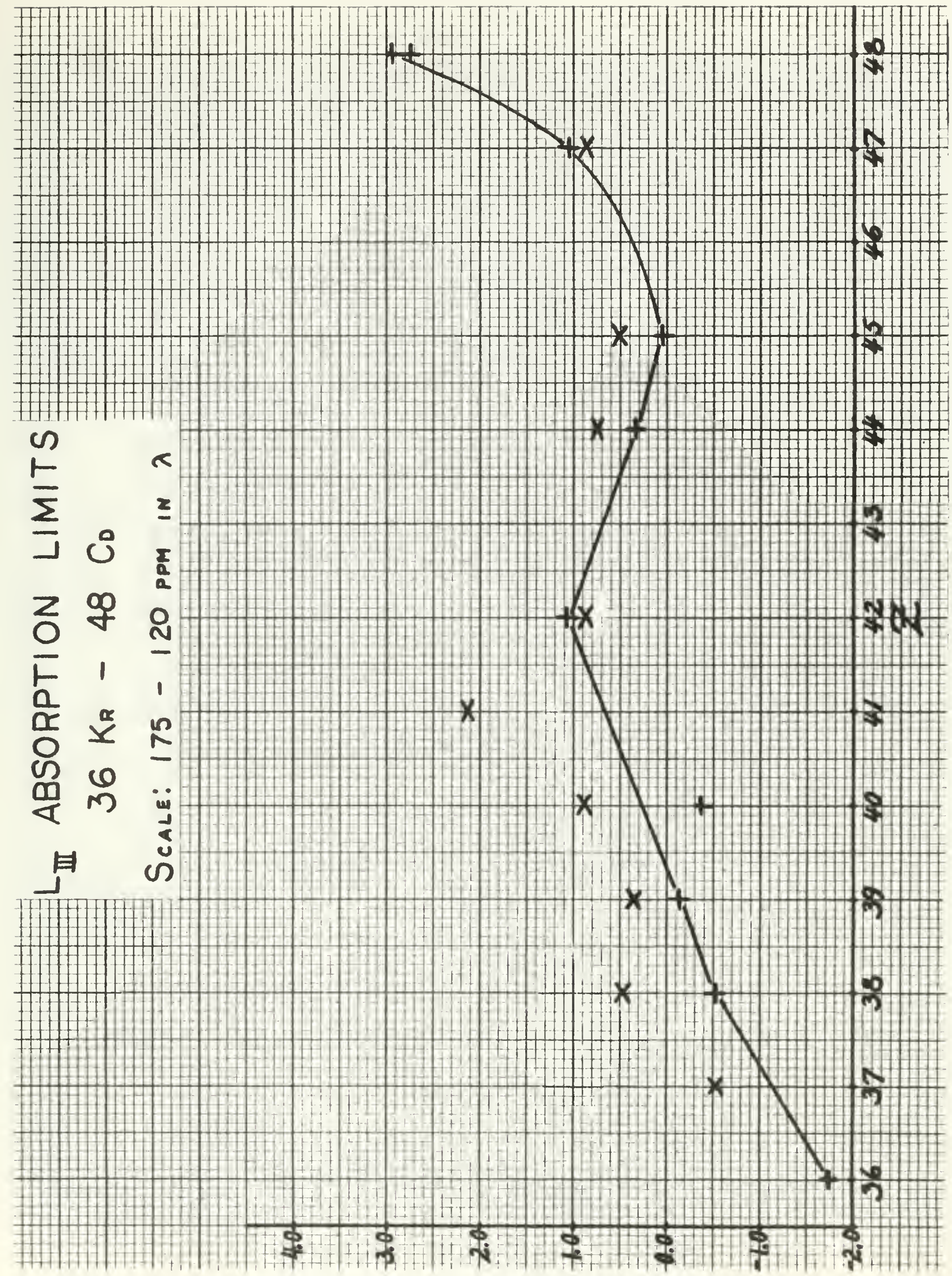

L_I ABSORPTION LIMITS
30 Zn - 38 Sr
Scale: 400 - 300 ppm in λ
$(\sqrt{\nu/R} \times 10^5) - (43.877 Z - 340.05)$
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
30
31
32
33
34
35
36
37
38
Z


L_{II} ABSORPTION LIMITS
26 Fe - 38 Sr
Scale: 520 - 315 ppm in λ
$(\sqrt{\bar{\nu}} \times 10^5) - (43.877\ Z - 402.21)$
25.0
24.0
23.0
22.0
21.0
20.0
19.0
18.0
17.0
16.0
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
26
27
28
29
30
31
32
33
34
35
36
37
38
Z

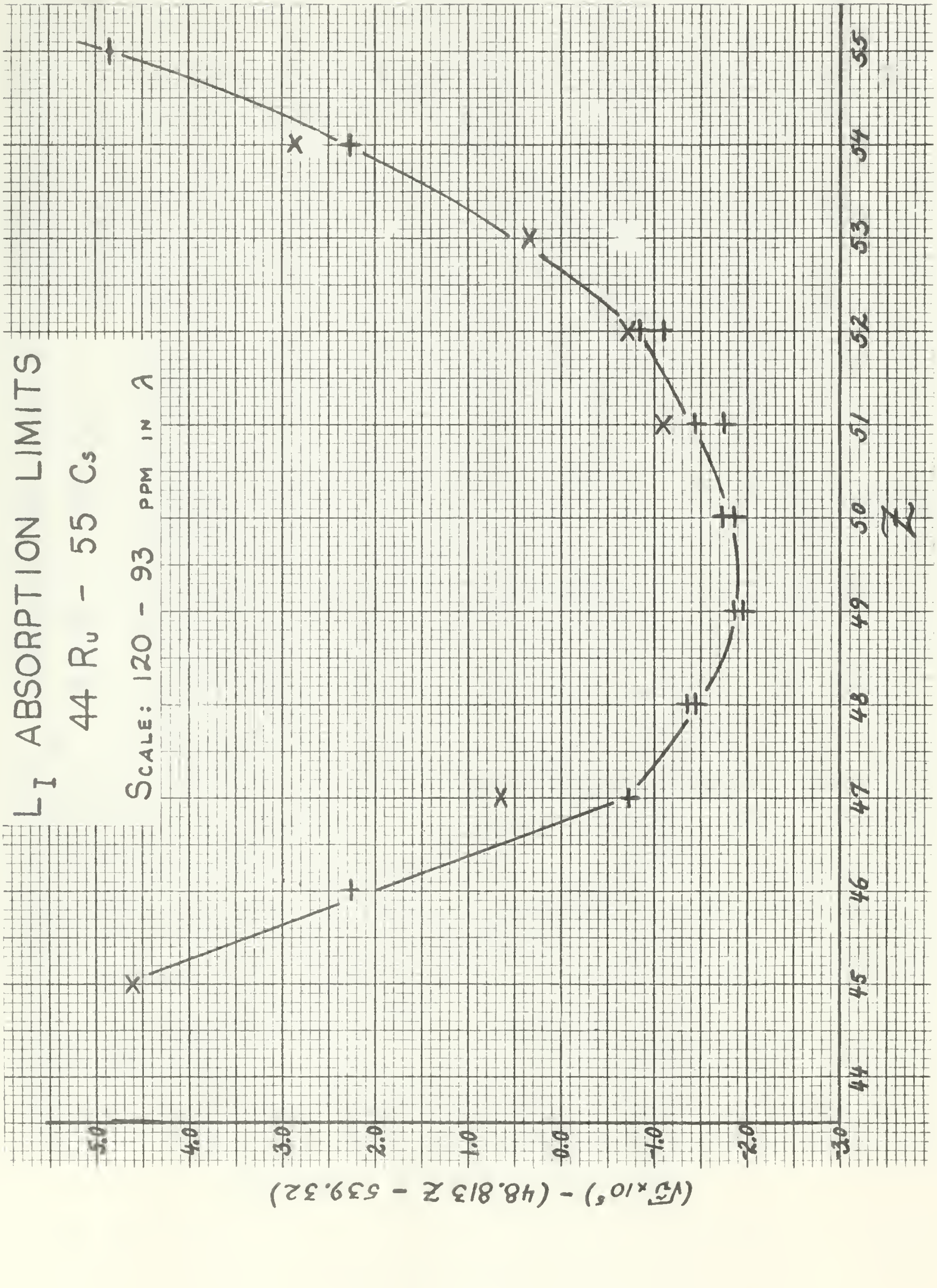

L$_{III}$ ABSORPTION LIMITS
26 Fe - 38 Sr
Scale: 530 - 320 ppm in λ
$(\sqrt{\nu} \times 10^5) - (4.17 Z - 324.72)$
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
26
27
28
29
30
31
32
33
34
35
36
37
38
Z

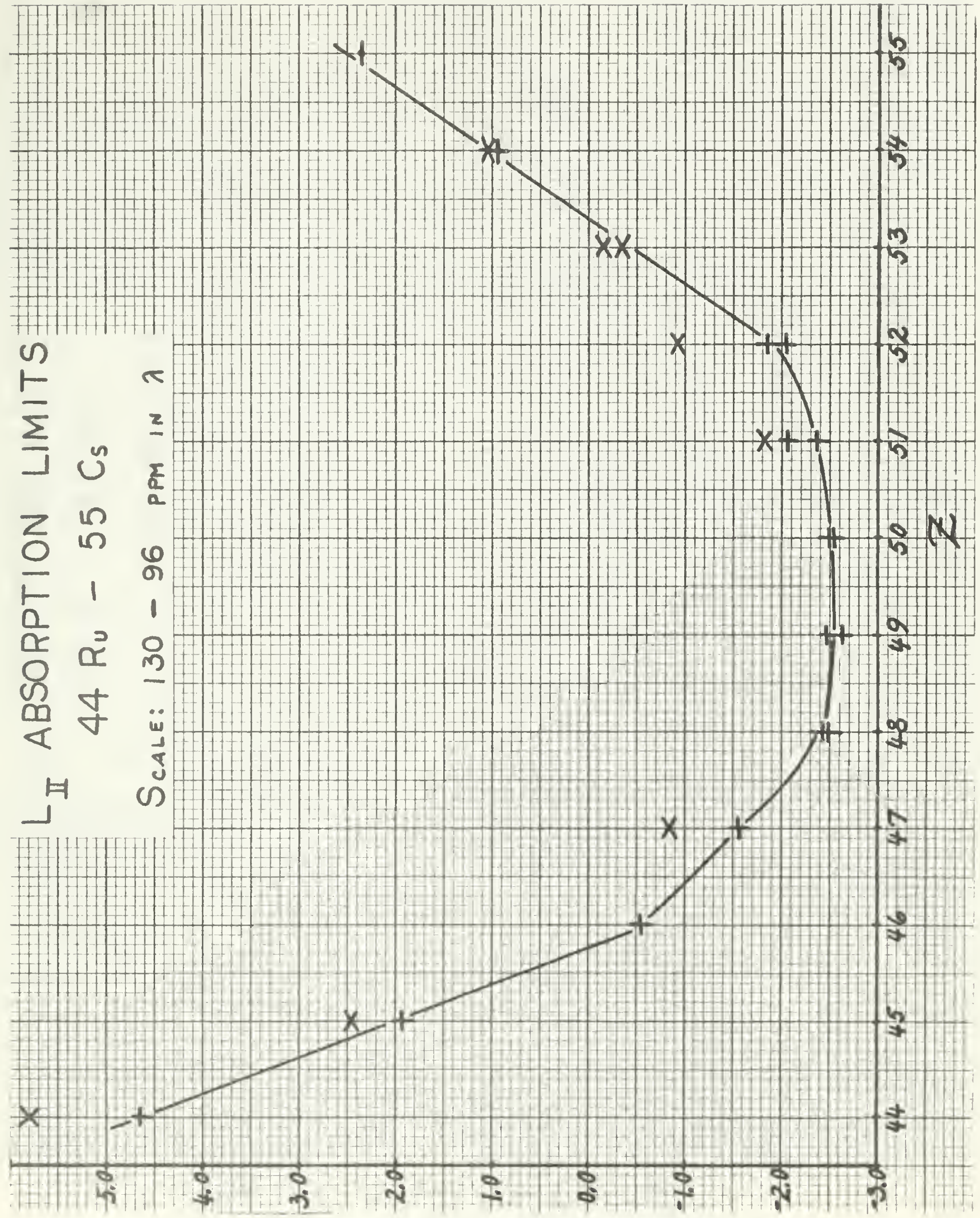

L_I ABSORPTION LIMITS
36 Kr - 48 Cd
Scale: 320 - 220 ppm in λ
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
-7.0
-8.0
-9.0
-10.0
-11.0
-12.0
$(\sqrt{\frac{\nu}{R}} \times 10^5) - (45.705 Z - 394.90)$
36
37
38
39
40
41
42
43
44
45
46
47
48
Z

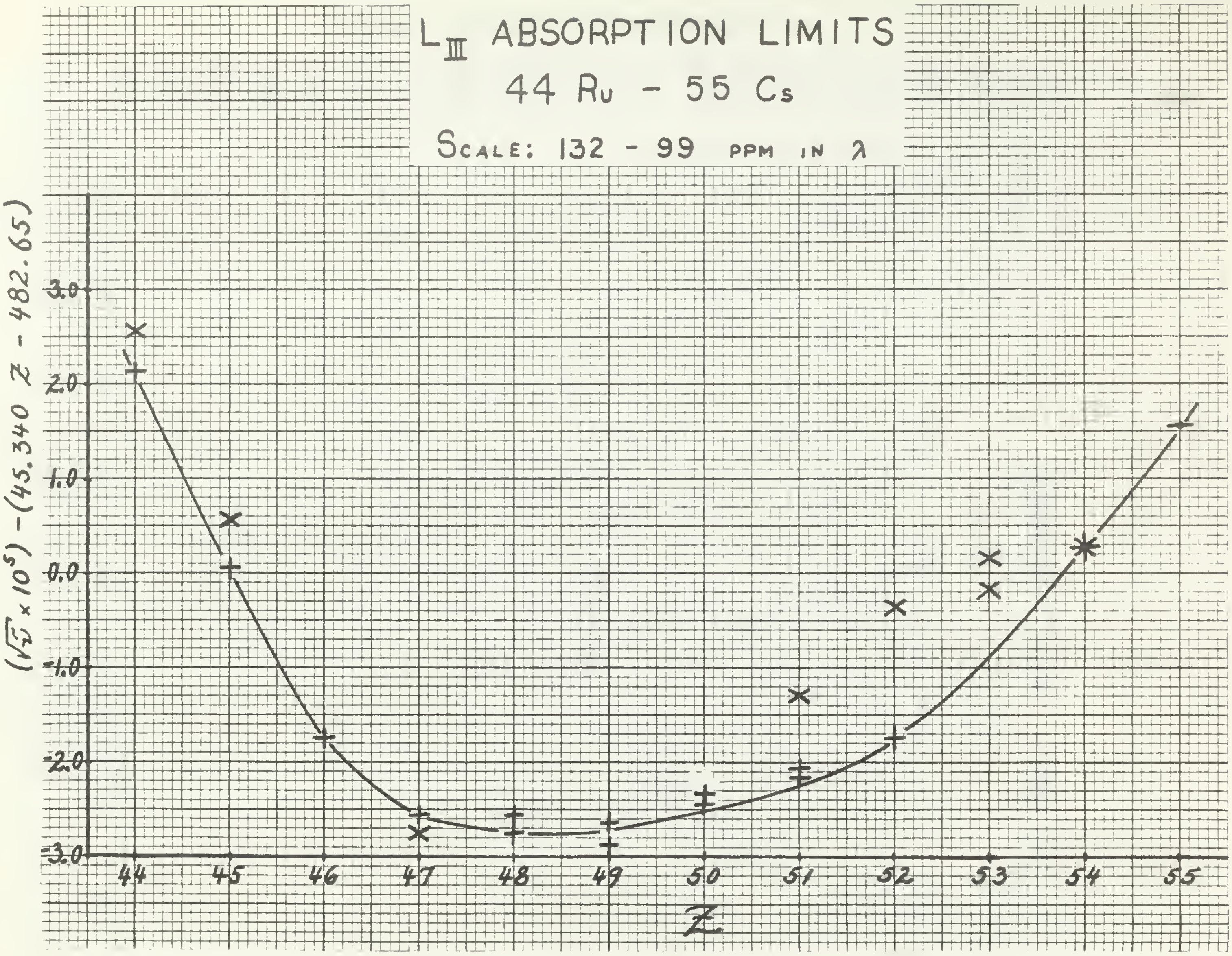

L II ABSORPTION LIMITS
36 Kr - 48 Cd
Scale: 170 - 115 ppm in λ
$(\sqrt{\frac{\nu}{R}} \times 10^5) - (45.705\ Z - 462.54)$
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
36
37
38
39
40
41
42
43
44
45
46
47
48
Z

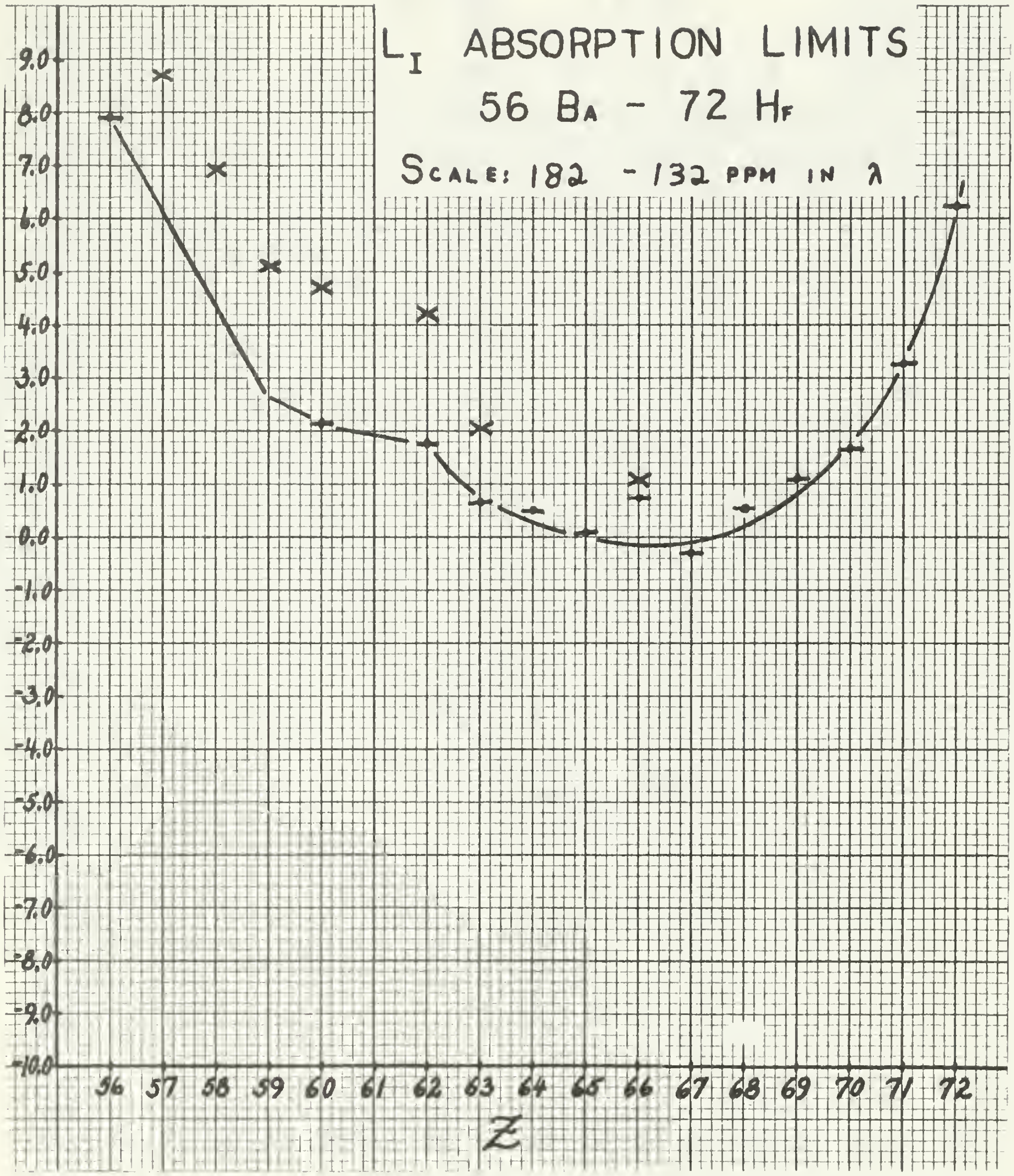


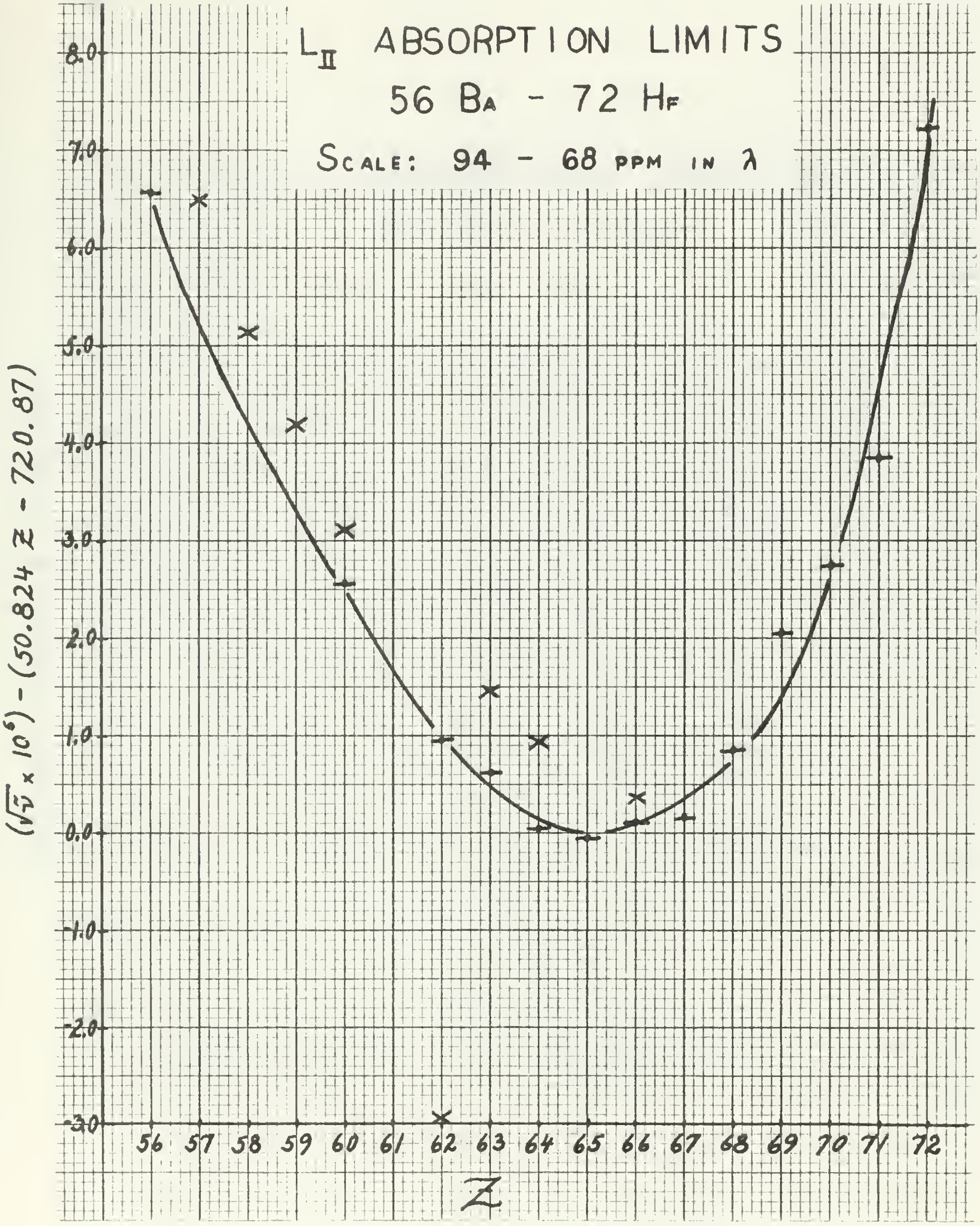
L_{III} ABSORPTION LIMITS
36 Kr − 48 Cd
Scale: 175 − 120 ppm in λ

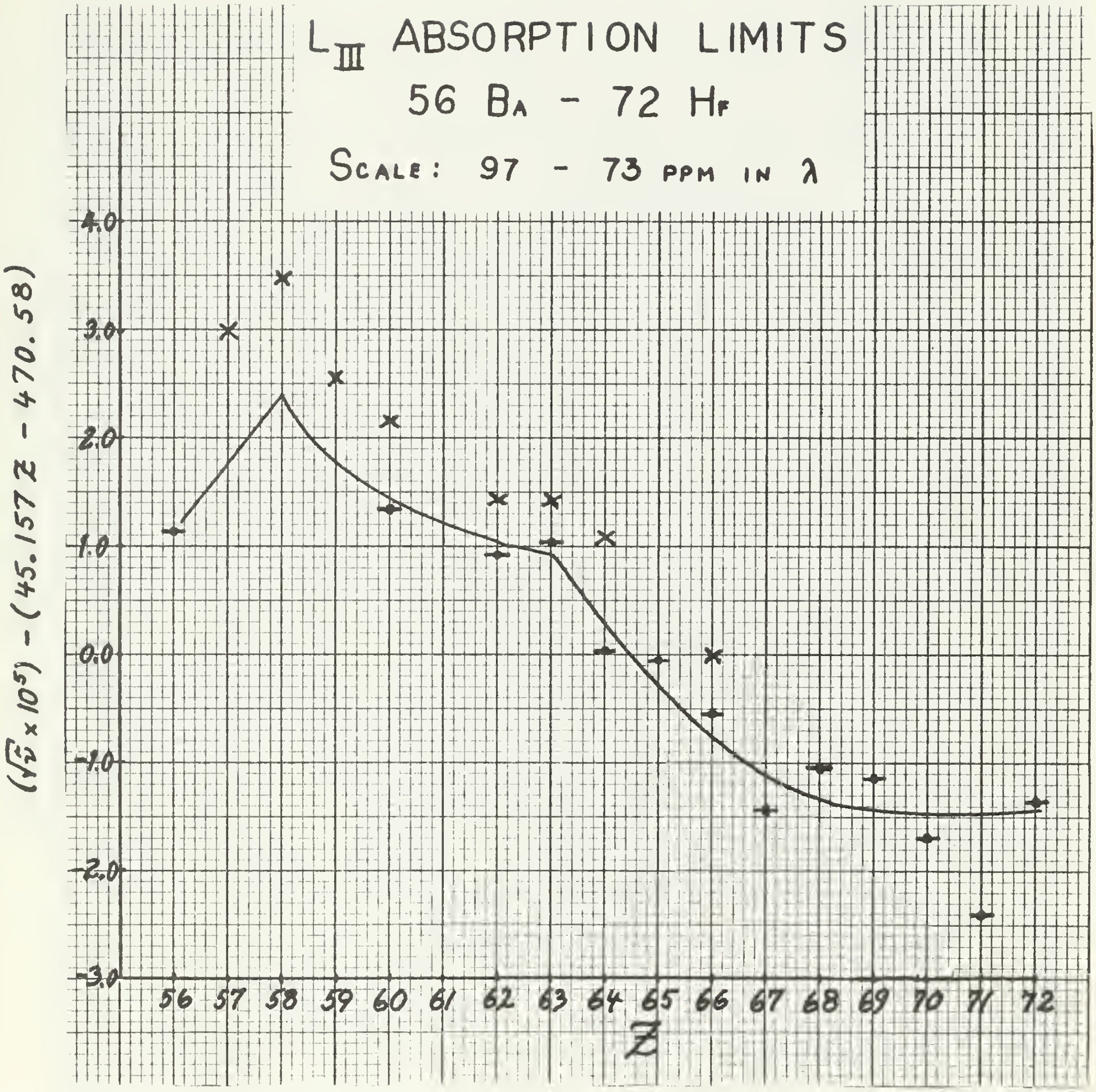

L_I ABSORPTION LIMITS
44 Ru - 55 Cs
SCALE: 120 - 93 PPM IN λ
44
45
46
47
48
49
50
51
52
53
54
55
Z
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
(√ν ×10⁵) - (48.813 Z - 539.32)

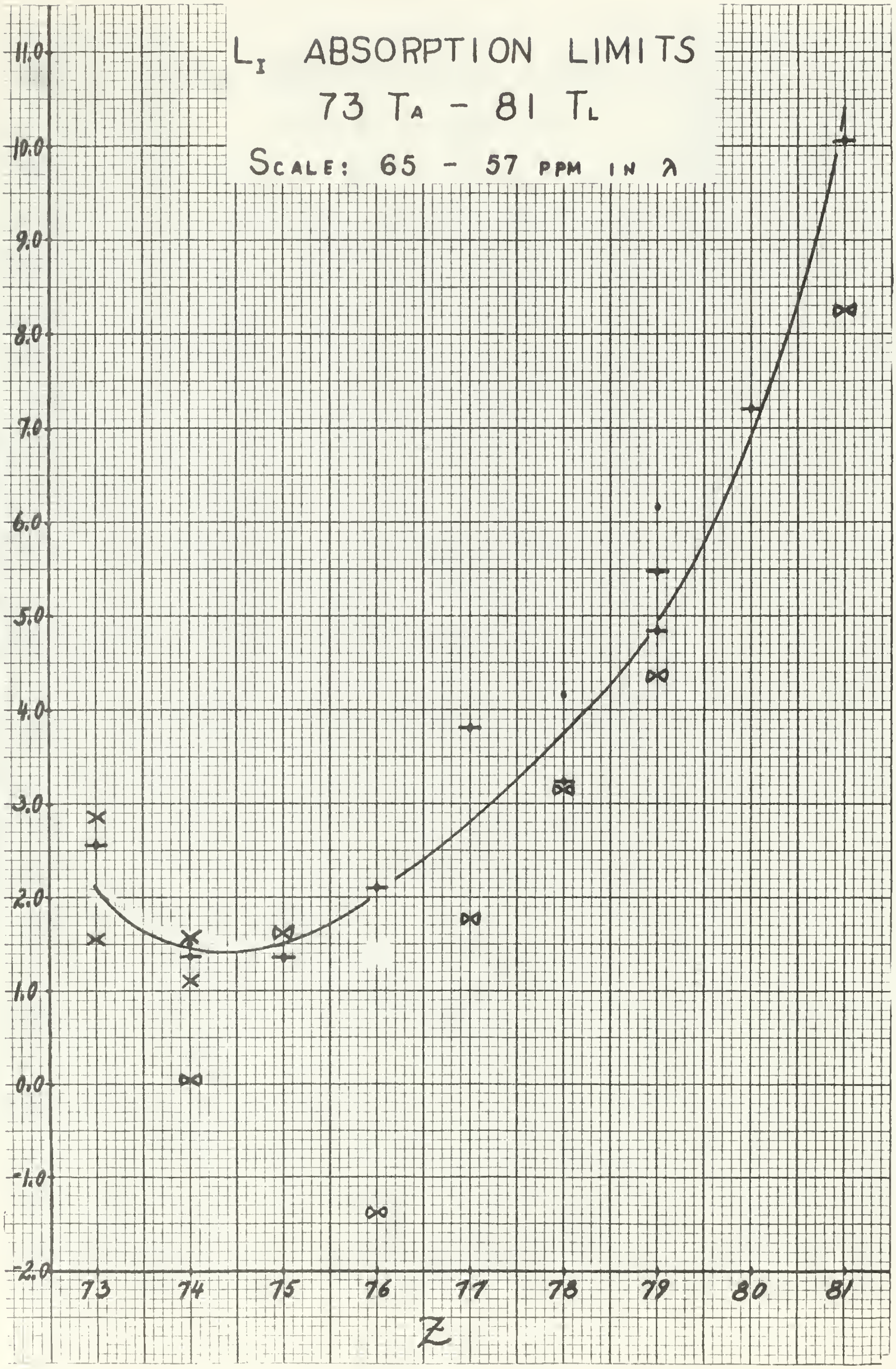

L_II ABSORPTION LIMITS
44 Ru - 55 Cs
Scale: 130 - 96 ppm in λ
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
44
45
46
47
48
49
50
51
52
53
54
55
Z
(1/ν × 10⁵) - (48.631 Z - 596.00)


L$_{III}$ ABSORPTION LIMITS
44 Ru - 55 Cs
Scale: 132 - 99 ppm in λ
$(\sqrt{\nu/R} \times 10^5) - (45.340\ Z - 482.65)$
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
44
45
46
47
48
49
50
51
52
53
54
55
Z


L_I ABSORPTION LIMITS
56 Ba - 72 Hf
Scale: 182 - 132 ppm in λ
(√ν x 10⁵) - (51.191 Z - 673.15)
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
-7.0
-8.0
-9.0
-10.0
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
Z


L$_{II}$ ABSORPTION LIMITS
56 Ba - 72 Hf
Scale: 94 - 68 ppm in λ
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
$(\sqrt{\nu} \times 10^5) - (50.824\,Z - 720.87)$
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
Z


L$_{III}$ ABSORPTION LIMITS
56 Ba - 72 Hf
Scale: 97 - 73 ppm in λ
$(\sqrt{\nu/R} \times 10^5) - (45.157Z - 470.58)$
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
Z


L$_I$ ABSORPTION LIMITS
73 TA - 81 TL
SCALE: 65 - 57 PPM IN λ
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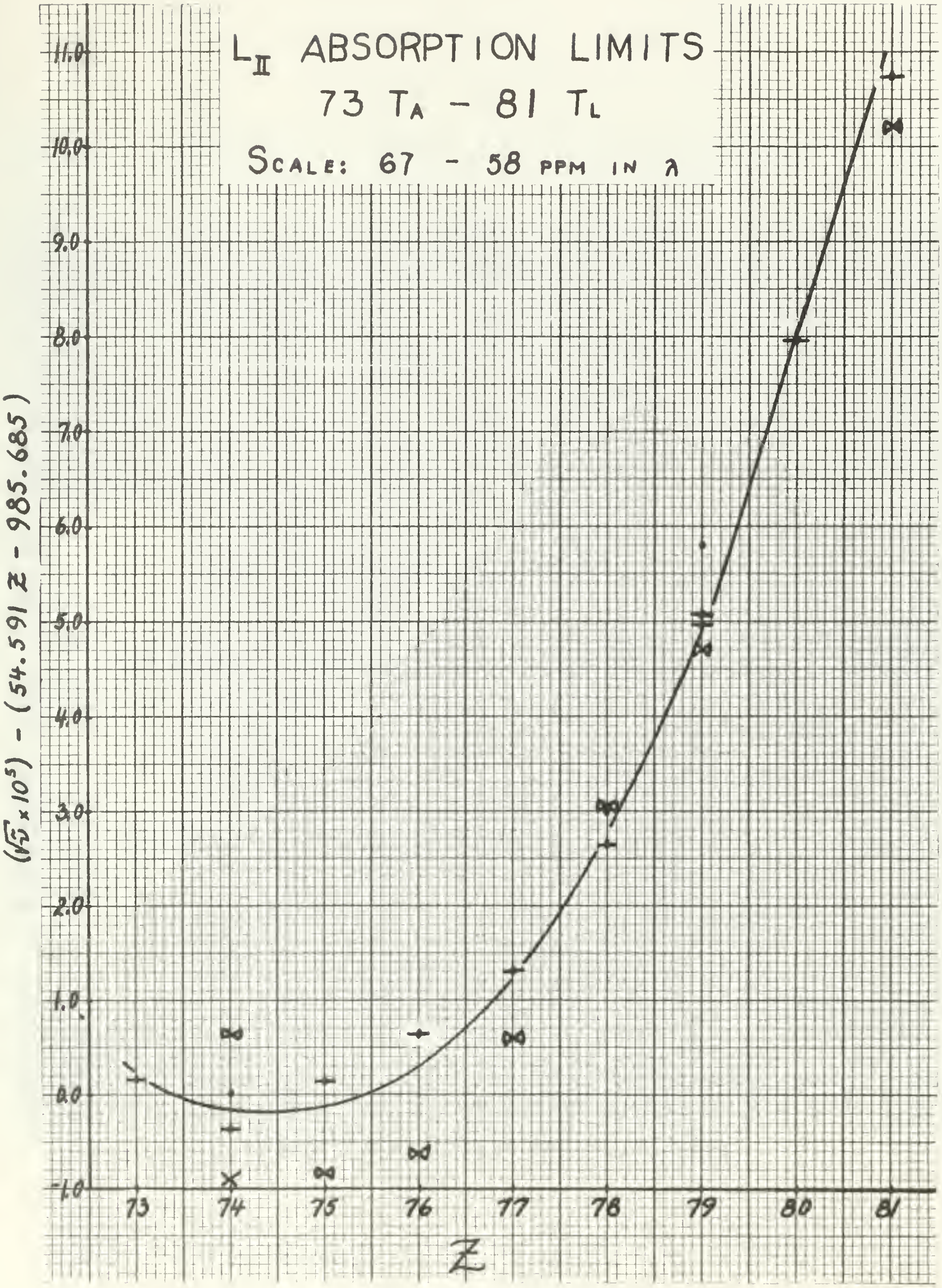
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
73
74
75
76
77
78
79
80
81
Z


L$_{II}$ ABSORPTION LIMITS
73 Ta - 81 Tl
Scale: 67 - 58 ppm in λ
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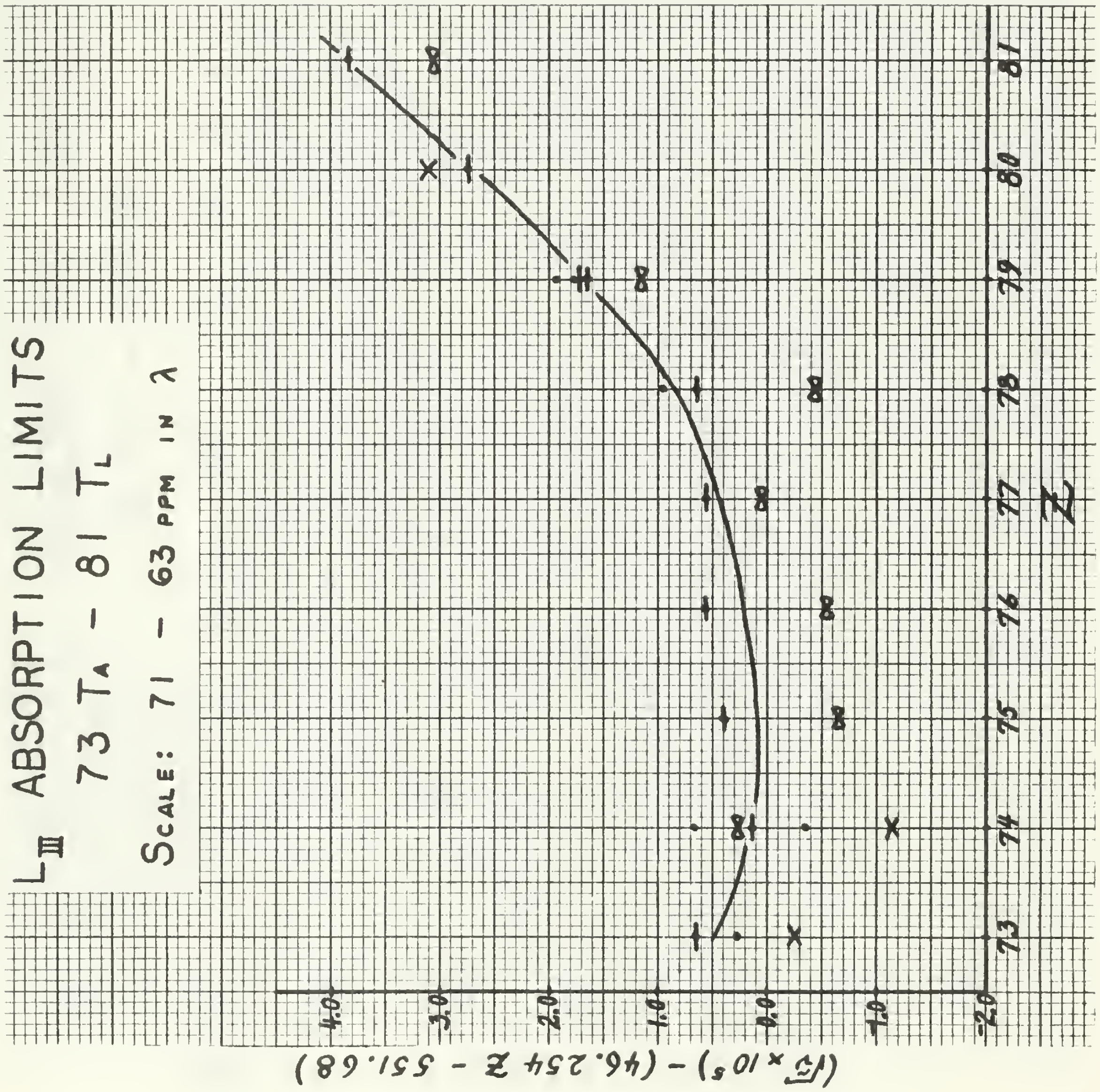
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
$(\sqrt{\nu} \times 10^5) - (54.591 Z - 985.685)$
73
74
75
76
77
78
79
80
81
Z


L_{III} ABSORPTION LIMITS
73 Ta - 81 Tl
Scale: 71 - 63 ppm in λ
4.0
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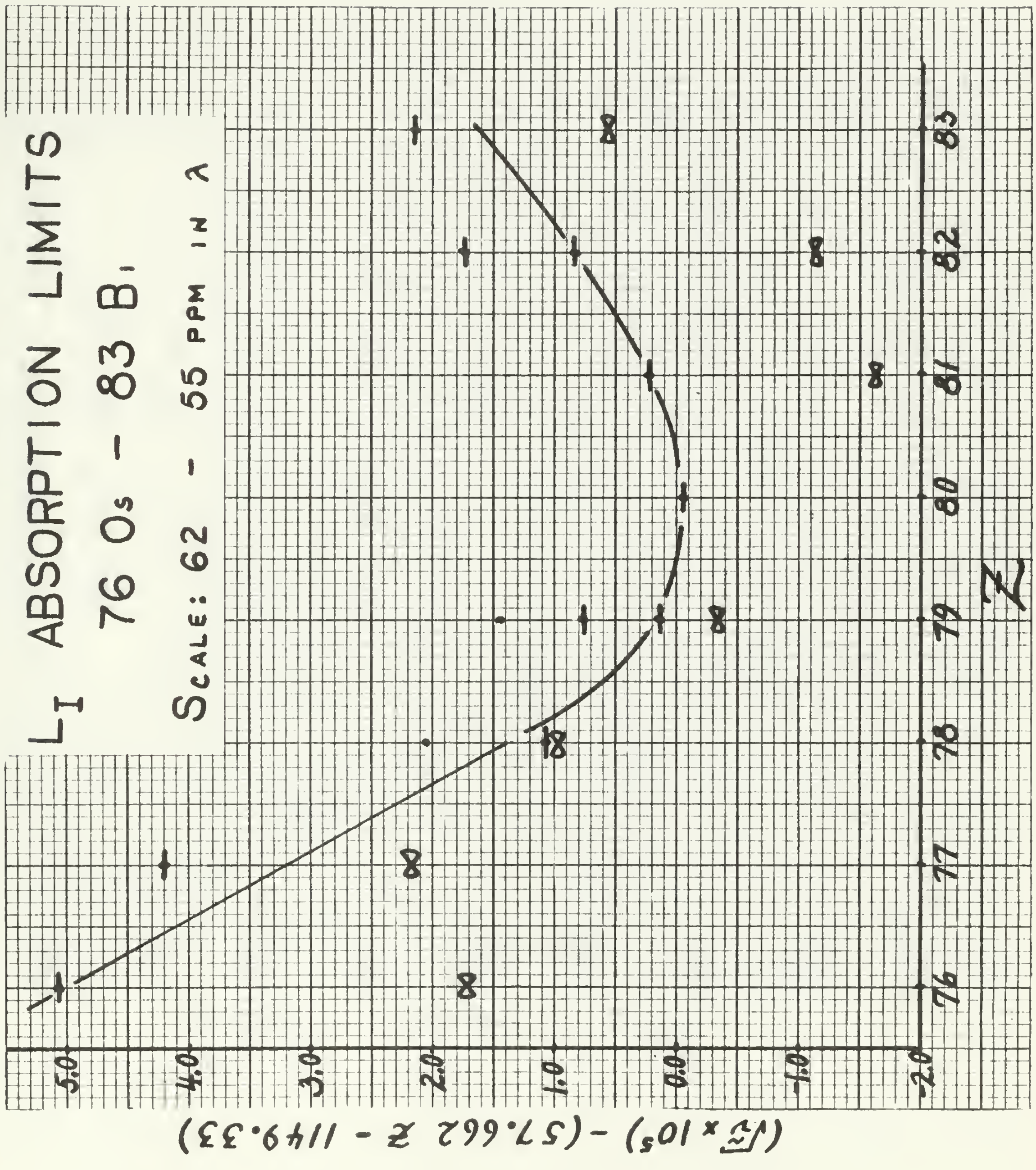
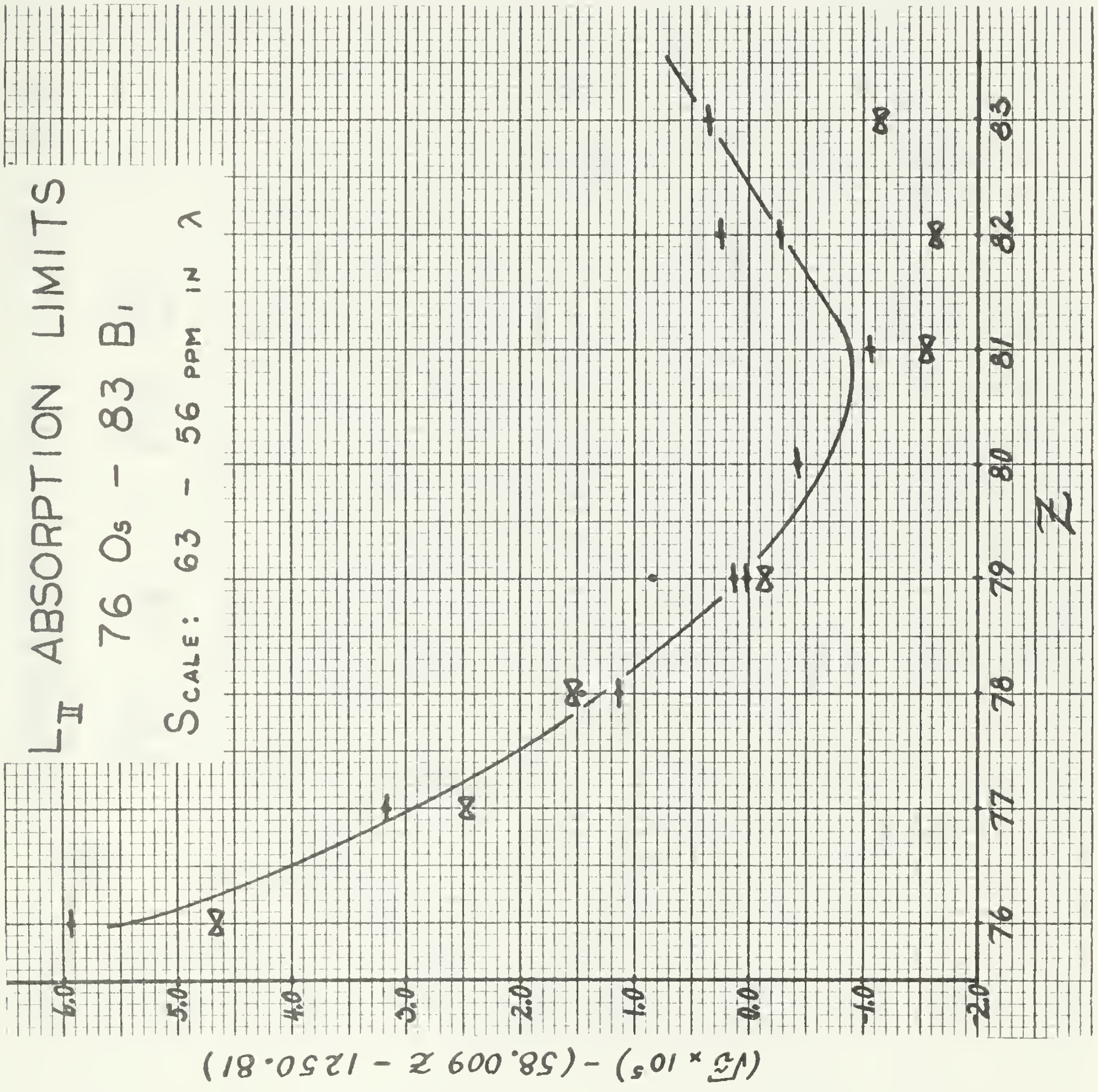
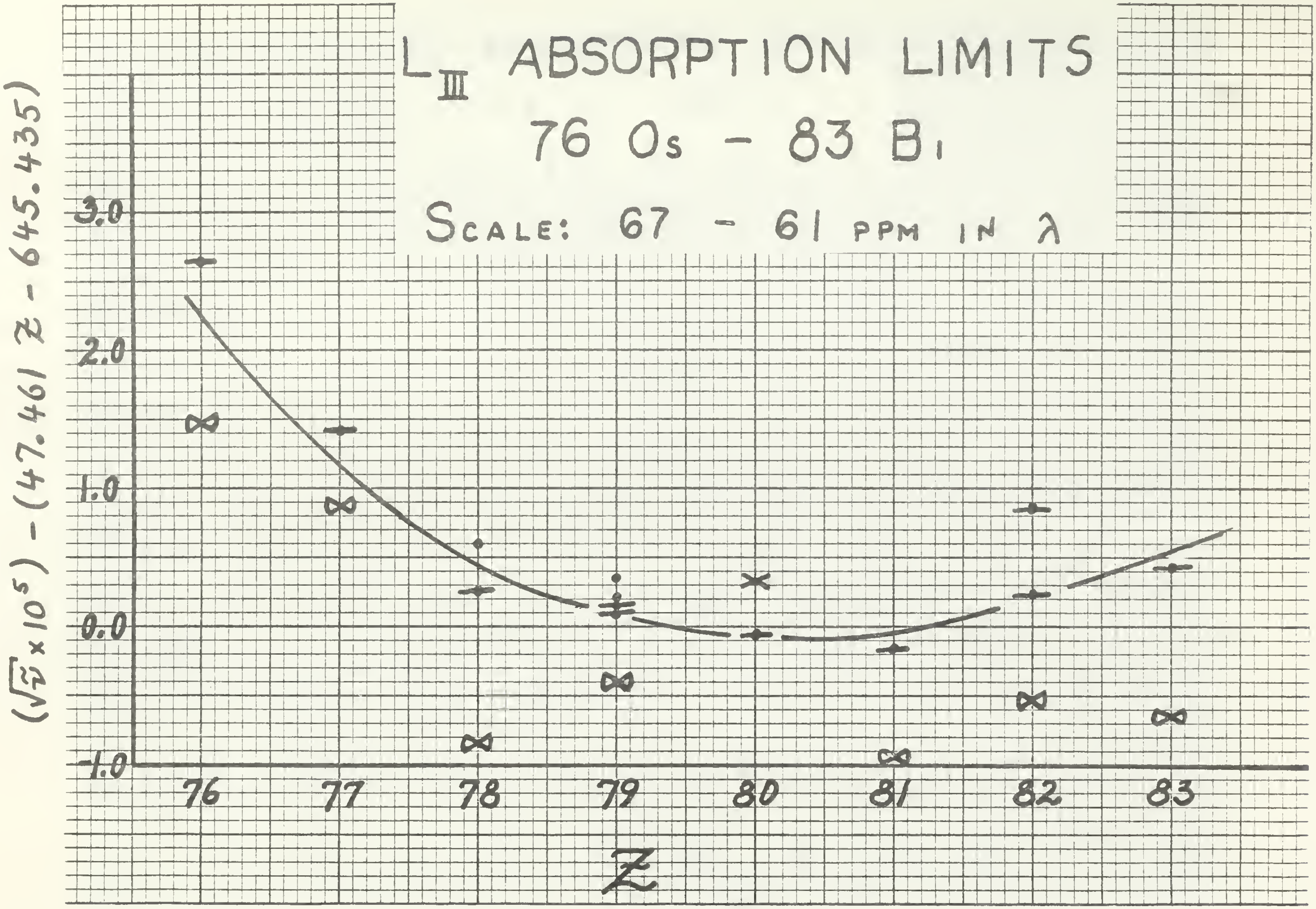
2.0
1.0
0.0
-1.0
-2.0
$(\sqrt{\nu/R} \times 10^5) - (46.254 Z - 551.68)$
73
74
75
76
77
78
79
80
81
Z



L_I ABSORPTION LIMITS
76 Os - 83 Bi
Scale: 62 - 55 PPM in λ


L_II ABSORPTION LIMITS
76 Os - 83 Bi
Scale: 63 - 56 ppm in λ
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
76
77
78
79
80
81
82
83
Z
(√ν/R × 10^5) - (58.009 Z - 1250.81)


L_III ABSORPTION LIMITS
76 Os - 83 Bi
Scale: 67 - 61 ppm in λ
(√ν/R x 10^5) - (47.461 Z - 645.435)
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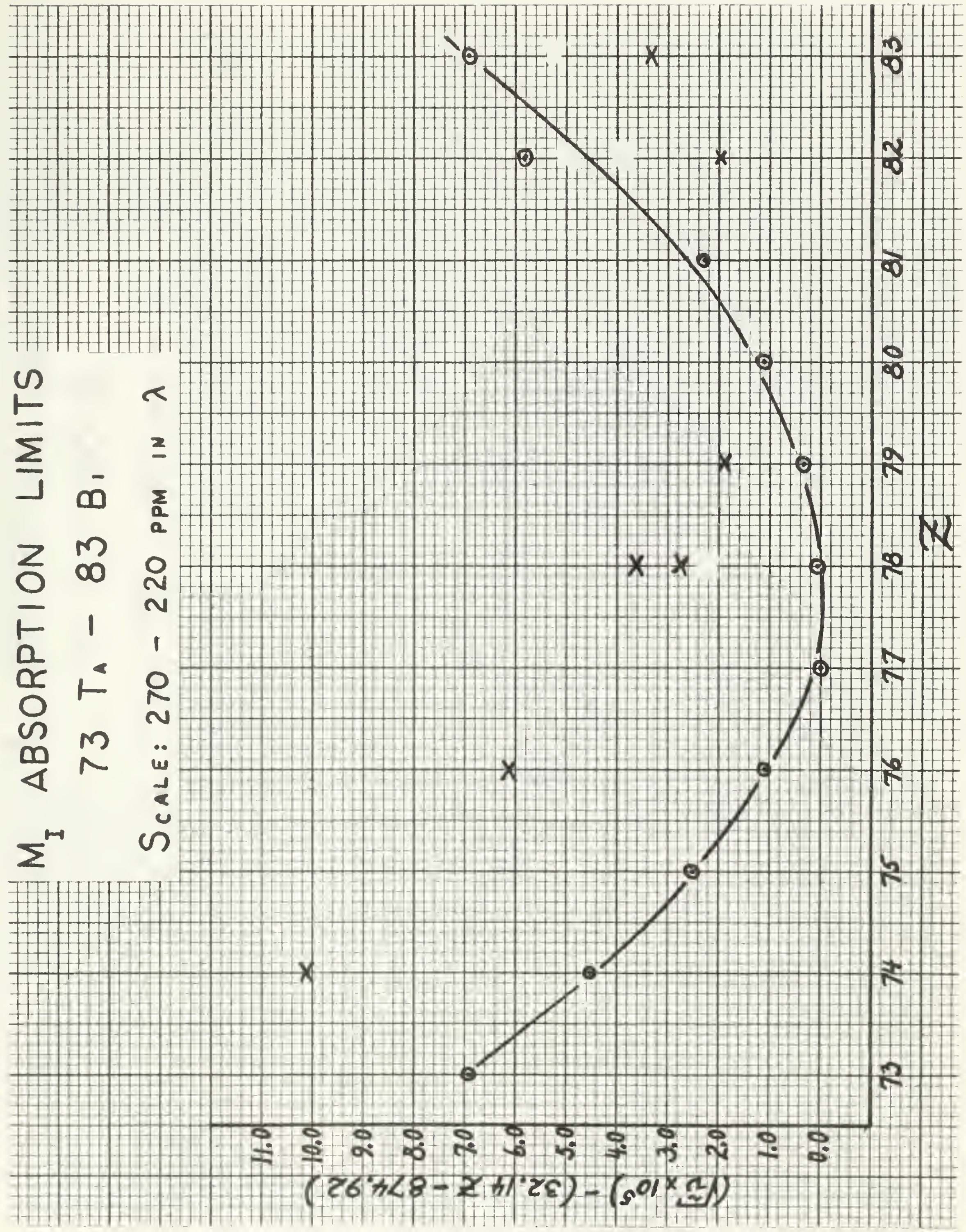
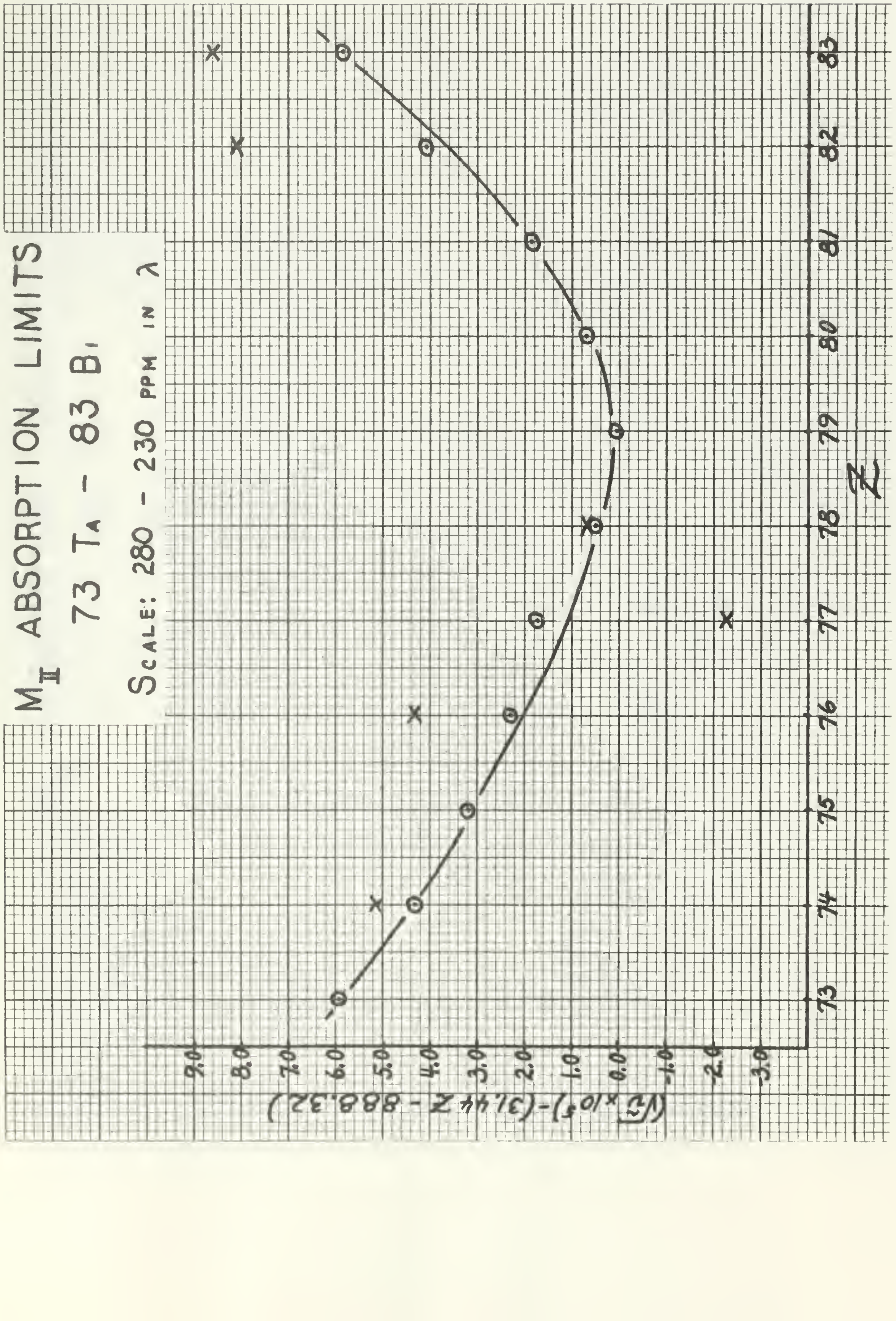
2.0
1.0
0.0
-1.0
76
77
78
79
80
81
82
83
Z

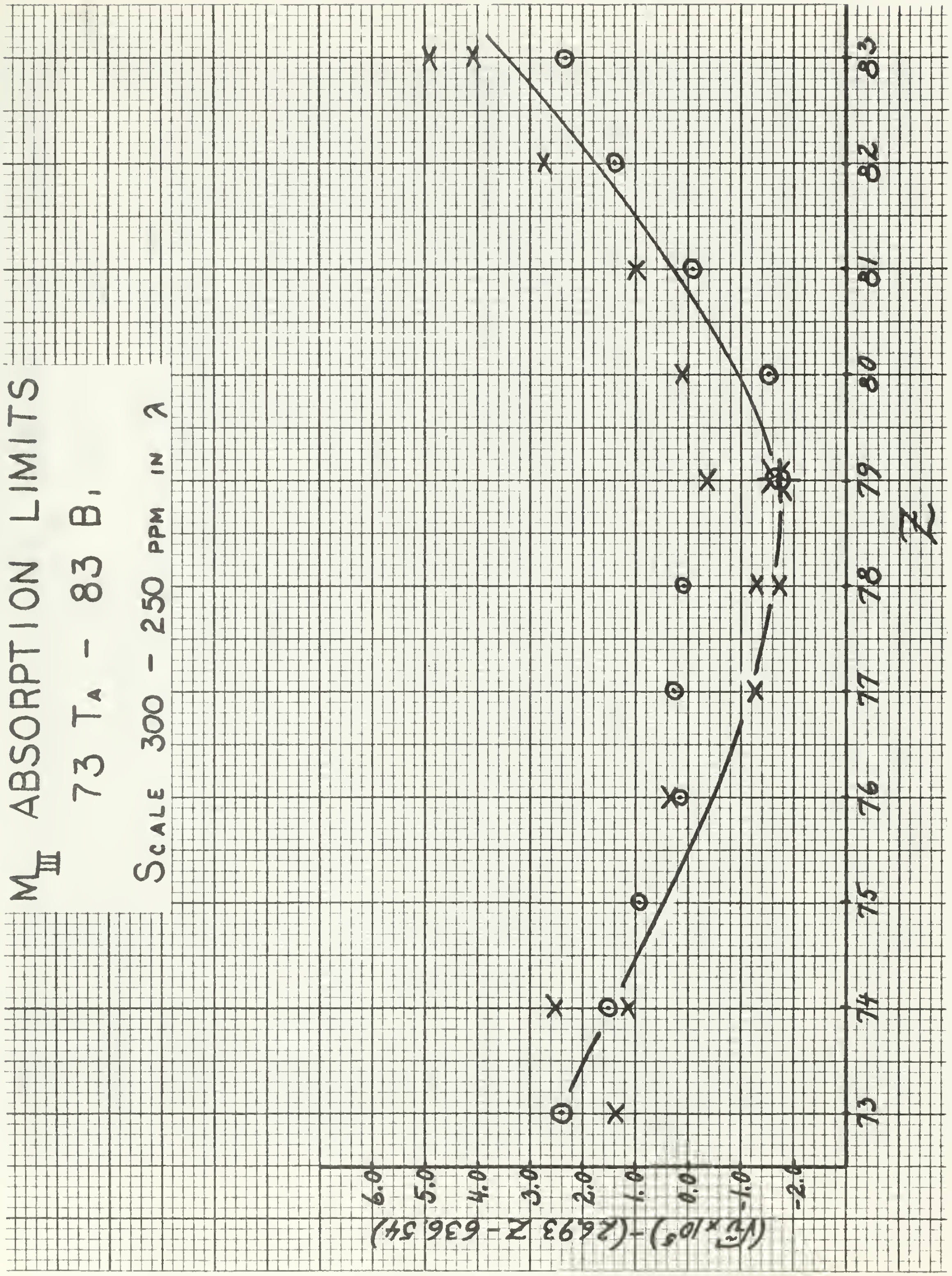

M$_I$ ABSORPTION LIMITS
73 Ta - 83 Bi
Scale: 270 - 220 ppm in λ
$(\sqrt{\frac{\nu}{R}} \times 10^5) - (32.14 Z - 874.92)$
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
73
74
75
76
77
78
79
80
81
82
83
Z



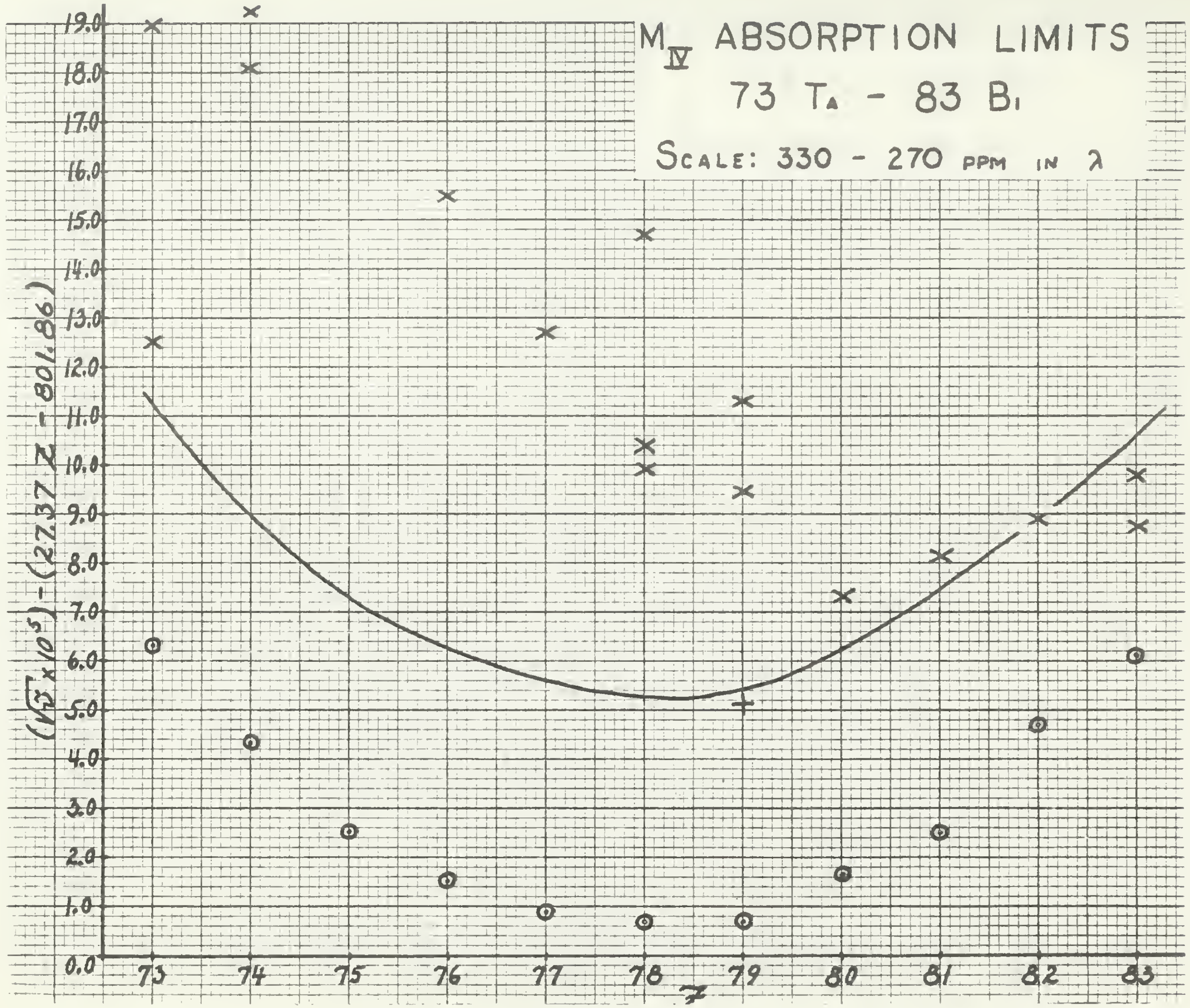
M_{II} ABSORPTION LIMITS

73 Ta - 83 Bi

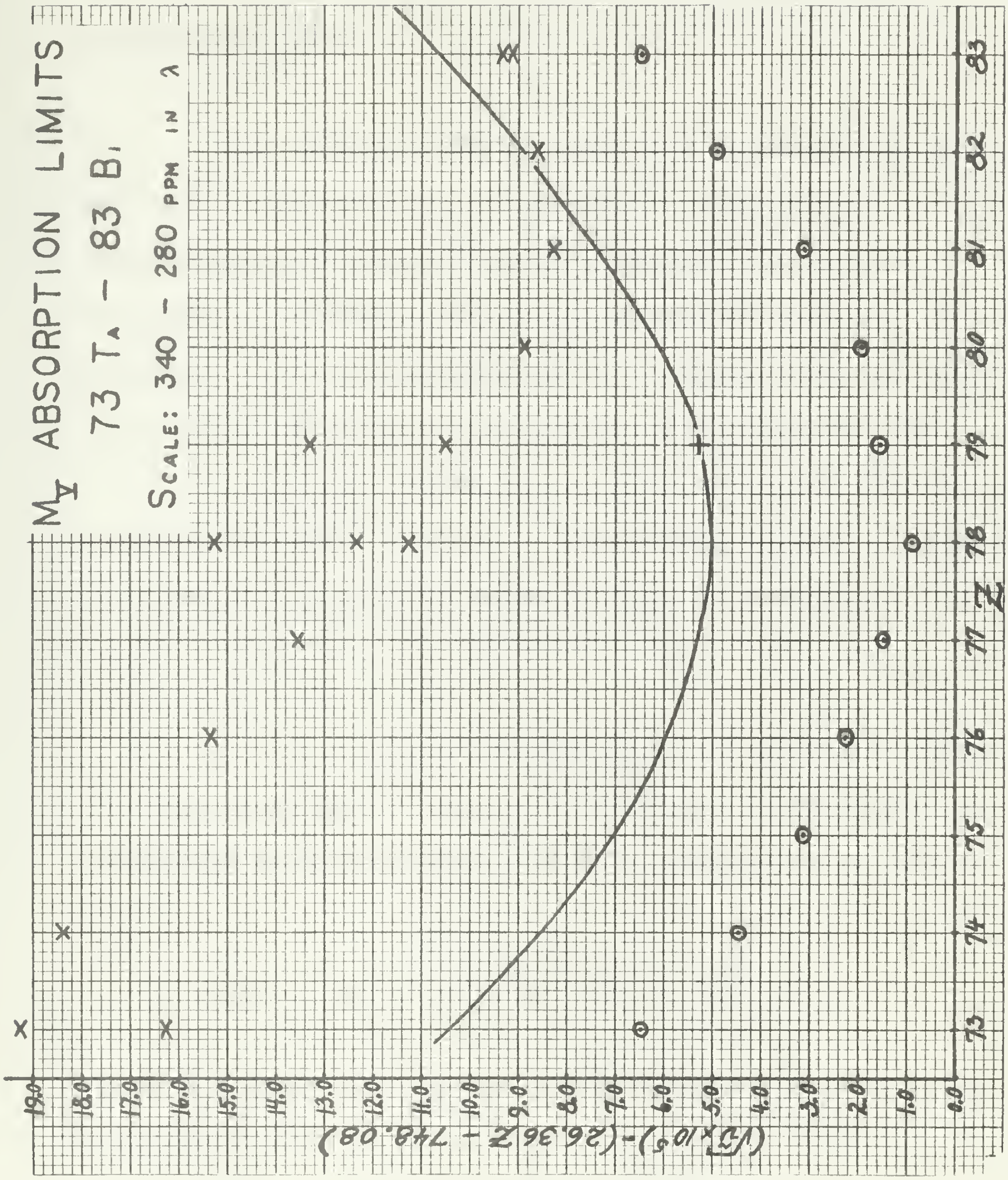
Scale: 280 - 230 ppm in λ



M_{III} ABSORPTION LIMITS
73 Ta - 83 Bi
Scale 300 - 250 ppm in λ



M$_{IV}$ ABSORPTION LIMITS
73 Ta - 83 Bi
Scale: 330 - 270 ppm in λ



M_V ABSORPTION LIMITS
73 Ta – 83 Bi
Scale: 340 – 280 ppm in λ

APPENDIX B

A Comparison of the Absorption Limit Values Determined from Coefficient of Absorption Curves with Those Obtained from Photometric Curves

The purpose of this appendix is to investigate the difference between the value of an absorption limit measured on a curve representing coefficient of absorption and that measured on a photometric recording representing transmitted intensity. In particular, we wish to substantiate the assumption that this difference is small compared to the precision of the measurements.

Let μ represent the coefficient of absorption for an absorber of thickness t, and let I_r represent the relative transmitted x-ray intensity, then by the exponential law of absorption,

$$I_r = e^{-\mu t} \qquad \text{(B-1)}$$

Based on the work of Richtmyer, Barnes and Ramberg (83), we assume that the absorption coefficient in the vicinity of a main edge can be represented by an arc-tangent curve, and we let

$$\mu(\nu) = K\left\{\frac{1}{2} - \frac{1}{\pi}\tan^{-1}\left(a[\nu_0-\nu]\right)\right\} + C \qquad \text{(B-2)}$$

where K, a, and C are constants, and ν_0 is the frequency of the absorption limit.

We first consider the absorption limit of frequency ν_1 on a curve representing the actual relative transmitted intensity

and look at the difference $\nu_0 - \nu_1 = \delta\nu$. From Eq. (B-1):

$$\frac{dI_r}{d\nu} = -t\,e^{-\mu t}\,\frac{d\mu}{d\nu}$$

and

$$\frac{d^2I_r}{d\nu^2} = t^2 e^{-\mu t}\left(\frac{d\mu}{d\nu}\right)^2 - t\,e^{-\mu t}\,\frac{d^2\mu}{d\nu^2}\,.$$

At $\nu = \nu_1$,

$$\frac{d^2I_r}{d\nu^2} = 0 = t\,e^{-\mu t}\left\{t\left(\frac{d\mu}{d\nu}\right)^2 - \frac{d^2\mu}{d\nu^2}\right\}$$

or

$$t\left(\frac{d\mu}{d\nu}\right)^2 = \frac{d^2\mu}{d\nu^2}\,. \tag{B-3}$$

From Eq. (B-2):

$$\frac{d\mu}{d\nu} = \frac{Ka}{\pi}\left[1 + a^2(\nu_0-\nu)\right]^{-1}$$

$$\left(\frac{d\mu}{d\nu}\right)^2 = \frac{K^2a^2}{\pi^2\left[1 + a^2(\nu_0-\nu)^2\right]^2}$$

and

$$\frac{d^2\mu}{d\nu^2} = \frac{2Ka^3(\nu_0-\nu)}{\pi\left[1 + a^2(\nu_0-\nu)^2\right]^2}$$

Substituting in Eq. (B-3) we obtain,

$$\frac{tK^2a^2}{\pi^2}\left(\frac{1}{\left[1+a^2(\delta\nu)^2\right]^2}\right) = \frac{2Ka^3}{\pi}\;\frac{\delta\nu}{\left[1+a^2(\delta\nu)^2\right]^2}$$

or

$$\frac{Kt}{\pi} = 2a\,\delta\nu$$

hence

$$\delta\nu = \frac{Kt}{2a\pi}\,. \tag{B-4}$$

In order to evaluate the constants K and a, let μ_h and μ_ℓ represent the limiting values of the absorption coefficient at the high and low energy sides respectively of the main edge, as shown in Fig. B1 below. (Fine structure is ignored here for purposes of this investigation.)

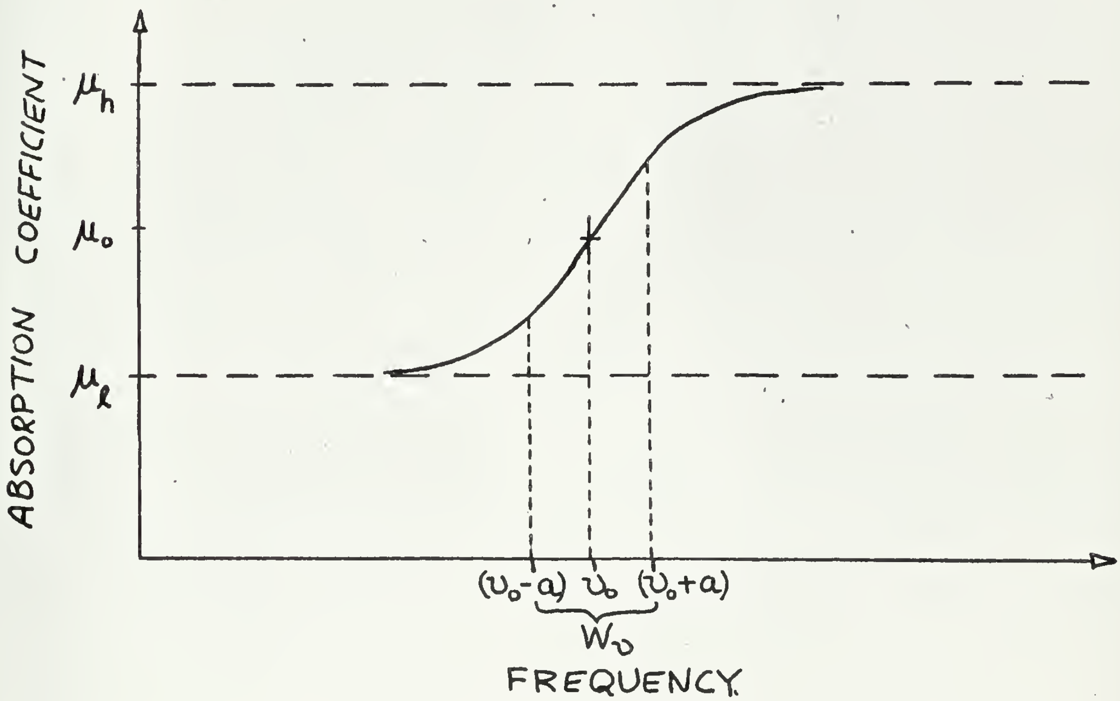


Fig. B1. A representative curve illustrating theoretical arc-tangent variation of the absorption coefficient with frequency in the region of a main absorption edge.

Looking at the asymptotic behavior of Eq. (B-2), we see that $C = \mu_\ell$ and $K = \mu_h - \mu_\ell$. Setting $\nu = \nu_0 + \frac{1}{a}$ in Eq. (B-2), we obtain

$$\mu(\nu_0 + \tfrac{1}{a}) = K\left\{\frac{1}{2} - \frac{1}{\pi}\tan^{-1}(-1)\right\} + C = \frac{3}{4}K + C$$

Similarly, when $\nu = \nu_0 - \frac{1}{a}$, we obtain

$$\mu(\nu_0 - \tfrac{1}{a}) = K\left\{\frac{1}{2} - \frac{1}{\pi}\tan^{-1}(+1)\right\} + C = \frac{1}{4}K + C$$

The constant term 2/a must therefore be equal to the width in frequency, W_ν, between 1/4 and 3/4 of the total jump in absorption coefficient at the main edge. According to the theory of Richtmyer, Barnes and Ramberg (83), this is just the width of the initial atomic level if the width of the final level is taken as zero.

Substituting now for K and a in Eq. (B-4), we obtain a theoretical expression for the difference between an absorption limit taken from an absorption coefficient curve and that taken from the corresponding curve of relative intensity, namely,

$$\delta\nu = \frac{t}{4\pi}(\mu_h - \mu_\ell)W_\nu \tag{B-5}$$

The difference $\delta\nu = \nu_0 - \nu_1$ is positive, hence the absorption limit obtained from an intensity curve will have the lower frequency, or longer wavelength. It is more convenient for the purpose of this discussion to speak in terms of wavelength, and since $\delta\nu / W_\nu \cong -\delta\lambda / W_\lambda$ (where $\delta\lambda = \lambda_0 - \lambda_1$ and W_λ is the width in wavelength units corresponding to W_ν), we shall make use of

the approximate expression,

$$\delta\lambda \cong -\frac{t}{4\pi}\left(\mu_h - \mu_\ell\right) W_\lambda \qquad \text{(B-6)}$$

It is impossible to evaluate δλ for all absorption limits, since the parameters on the right in Eq. (B-6) depend on the element and the transition in question, as well as on the absorber thickness used. Furthermore, there are very few papers in the literature which include the data needed to calculate its value for specific limits. However, from a few examples where such data is available, some conclusions can be drawn concerning the magnitude of δλ.

The most interesting of the papers which provide sufficient information for calculating δλ is the recent report by Beckman, Axelsson and Bergvall (6) on their detailed study of the effect of the spectrometer window on the K edge of gold. Figure 2 in this paper shows a comparison of the experimental intensity variation at the gold K limit and the corresponding variation in absorption coefficient obtained for a gold foil of thickness t = .0985 mm. The inflection point of the intensity curve is shown here to be of approximately .026 xu longer wavelength than the inflection point of the corresponding absorption coefficient curve, which, within experimental errors, has an arctangent variation. The asymptotic values μ_h = 16.2 mm^{-1} and μ_ℓ = 5.49 mm^{-1} were very carefully determined by Beckman et al., using several absorbers

of various thicknesses and are published in the report, while $W_\lambda = 0.14$ xu can be read directly from the figure. When these values are substituted in Eq. (B-6), we obtain a theoretical result of $\delta\lambda \cong -.011$ xu, which is in reasonable agreement with the experimentally observed difference, when one considers that the estimated limit of error given by Beckman et al. is ± .010 xu in the determination of the absorption limit wavelength.

Although the value of $\delta\lambda$ is essentially equal to the uncertainty of the Au K absorption limit wavelength, it should be noted that this limit is known with considerably greater accuracy than are the K limits of most other elements in this region. This is due to the care taken by Beckman, Axelsson and Bergvall in eliminating the effect of absorber thickness, as well as their use of absorption coefficient curves, which, as previously pointed out, are considered the preferable method from a theoretical standpoint. For the case of most other K limits in this region, where photographic measurements have been involved and where the effect of absorber thickness has been neglected, the estimated uncertainty is about four times the magnitude of $\delta\lambda$ calculated above for gold.

The only paper reviewed in the course of this study which contained an actual comparison of intensity and corresponding absorption coefficient curves was the one just discussed; however, Nordfors and Noreland (77) have included absorption coefficient curves of several L limits, from which approximate

values can be taken for calculating $\delta\lambda$. The results obtained from some of these curves are included in Table B1, which also includes an estimate of the uncertainty in recommended wavelengths for the particular region in question. The curves representing absorption at the L_{II} edge were not evaluated in this case, as they appear to be distorted from the overlapping fine structure of the L_{III} edge and do not generally reflect an arctangent variation.

Table B1

Element	Limit	xu $\delta\lambda$	$\frac{\delta\lambda}{\lambda_r}$ x10^6	Approx. uncertainty of λ_r in the region	Ref.
Au	K	-.011	72 ppm	300 ppm	6
Cd	L_{III}	-.082	23	100	77
Sn	L_I	-.083	30	100	77
Sn	L_{III}	-.108	34	125	77

In each of the above examples, the theoretical difference between the absorption limit from an absorption coefficient curve and that from the corresponding curve of relative intensity is less than a third the estimated uncertainty in the recommended values for absorption limits in that particular region. While this is admittedly a very limited sampling upon which to draw a general

conclusion, it nevertheless supports the assumption that this difference is small compared to accuracy of the measurements; no examples could be found to contradict this assumption. In addition, it seems safe to assume that the term $t(\mu_h - \mu_\ell)$ in Eq. (B-6) will normally be of the order 1 in order to obtain optimum contrast at the absorption edge, and thus $\delta\lambda$ will be roughly 15 per cent of the width of the initial atomic level. Since the accuracy of a measurement generally depends on the breadth of the curve representing the edge, it appears reasonable to conclude that the relationship between uncertainty of the measurements and $\delta\lambda$ found for the above examples is representative of the general case.

Strictly speaking, the photometric curves are not true curves of relative transmitted intensity, due primarily to the variations with wavelength of incident intensity and the film blackening characteristics. As far as the absorption limit measurements are concerned, however, we are interested in a very small portion of the curve, covering only a few x units in wavelength, so that these effects are very small and can reasonably be neglected. This follows, first of all, from the fact that x ray target materials are normally selected so as to minimize the variation of the incident intensity within the wavelength region of the discontinuity to be studied. Secondly, since film density is essentially a linear function of exposure in the x ray region,

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variation in blackening is principally due to the change in energy of photons striking the photographic emulsion; this change is certainly not significant between the high and low energy sides of a main edge.

In conclusion, it should be added that the difference, $\delta\lambda$, is opposite in direction to the shift in the absorption limit caused by finite thickness of the absorbing screen. This effect was only recently recognized, and consequently very few intestigators have taken it into consideration. Hence, it is even possible that the absorption limit values obtained from photometric readings are actually more accurate than the majority of those obtained from absorption coefficient curves.

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Biographical Sketch

The author was born February 19, 1935 in Chagrin Falls, Ohio, where he attended public school until 1953. His undergraduate work was done at the United States Naval Academy, Annapolis, Maryland, where he received a Bachelor of Arts degree in naval science and was commissioned an Ensign in the U.S. Navy in 1957.

Following graduation from the Naval Academy, Mr. Matthews served for three years in the engineering department on board the USS HUGH PURVIS (DD709), a destroyer based in Newport, Rhode Island. He was assigned as a student in naval engineering at the U.S. Naval Postgraduate School in Monterey, California in 1960, and in 1961 was transferred to The Johns Hopkins University in Baltimore, Maryland for graduate studies in physics.

Upon completion of two years of study at The Johns Hopkins University, Mr. Matthews, now a Lieutenant, was assigned to his present duty station as Engineering and Electronic Maintenance Officer on the staff of Commander Destroyer Squadron Eight in Mayport, Florida.

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